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## **In-Situ Subsurface Coating of Corroded Steel Sheet Pile Structures**

Final Report on Project F08-AR06

Alfred D. Beitelman, Richard G. Lampo, Lawrence Clark,  
Dave Butler, Eric Van Draege, and David Rozène

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# In-Situ Subsurface Coating of Corroded Steel Sheet Pile Structures

Final Report on Project F08-AR-06

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Final report

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## Abstract

The Department of Defense (DoD) spends over \$100 million annually maintaining and repairing waterfront infrastructure, including corroded steel sheet pile structures located in warm, salt-water immersion and areas susceptible to accelerated low-water corrosion. Once designed as temporary structures, many now support permanent requirements and must be repaired in place. Conventional underwater repair and coating operations are accomplished by specialized divers at very high cost. This project investigated a cost-saving emerging technology called a limpet cofferdam, which is readily positioned below the waterline to provide workshop-like conditions for repair technicians, and is rapidly movable along submerged sheet pile structures. Also demonstrated was a highly durable, single-coat amine epoxy system that fully cures in immersion.

Limpet deployment and dewatering was completed in 30 minutes or less, and leaks into the workspace through damaged sheet pile were sealed in 5–30 minutes, depending on perforation size and other variables. The coating was found to be readily sprayable with only minimal pinholing, and fully cured under water. Literature indicates that this coating can be expected to have a 25–30 year service life. The calculated return on investment for these technologies is 14.70, with higher potential return when planning includes the recommended site-assessment methods.

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## Preface

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Prevention and Control Project F08-AR06, "In Situ Coatings for Sheet Piles." The proponent was the US Army Office of the Assistant Chief of Staff for Installation Management (ACSIM), and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)), Bernie Rodriguez (IMPW-E), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Engineering and Materials Branch (CEERD-CFM), Facilities Division (CF), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. The ERDC-CERL Project Manager was Alfred D. Beitelman. Portions of this work were performed under contract by Mandaree Enterprise Corporation (Warner Robins, GA) and Acotec, Inc. (Erembodegem, Belgium and Houston, TX). The ERDC-CERL CPC Program Manager was Michael K. McInerney. At the time this report was prepared, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF, and Kurt Kinnevan, CEERD-CZT, was the Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL is Dr. Kirankumar Topudurti and the Director is Dr. Ilker Adiguzel.

Daniel Zrna, Department of Public Works, Torii Station, Okinawa, is gratefully acknowledged for his support and assistance in this project.

The Commander of ERDC is COL Bryan S. Green and the Director is Dr. David W. Pittman.

## Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
mils	0.0254	millimeters
square feet	0.09290304	square meters

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# 1 Introduction

## 1.1 Problem statement

The Department of Defense (DoD) annually spends over \$100 million maintaining and repairing piers, wharfs, and shore erosion-protection facilities (Herzberg et al. 2014). The steel sheet piles typically used in the construction of these facilities have usually been installed without protective coatings. Historically, they were considered temporary structures, so target design life has been achieved by specifying steel thick enough to withstand expected environmental stresses and corrosion. However, after many decades of experience with sheet pile material failures in highly corrosive environments, such as warm salt-water immersion or areas susceptible to accelerated low-water corrosion (ALWC), it is apparent that sheet pile structures must be designed and maintained for the long term in order to control DoD maintenance and repair costs.\*

The destructive impacts of ALWC have become more well understood in recent years. ALWC is a localized and aggressive form of corrosion that occurs at or below the low-water level of a structure and is associated with microbially induced corrosion. ALWC develops suddenly after 10 years of slow corrosion. This corrosion progresses to a point where wall section thinning starts to compromise the integrity of the structure. Averaged over time, ALWC corrosion rates are typically 20 mil (0.5 mm)/side/year, to the point of complete perforation of steel plate. This damage directly affects mission-critical operations in docks and other marine structures supported by rapidly corroding sheet piles.

Conventional in situ repair and coating processes for sheet pile structures can be accomplished only by divers at an extremely high cost. Recent innovations by several companies have produced portable limpet cofferdams that can be immersed alongside sheet pile structures, then dewatered so work on the piles conducted in a dry environment. Industry has also produced hundred-percent-solids epoxy coatings that rapidly and effectively cure in damp, humid environments so the cofferdam structure can be

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\* Literature documenting sheet pile material failures include CEBELCOR 1987; Christie 2000; Gehrke and Sand 2003; Kumar and Stephenson 2002, 2005, 2006; PIANC Working Group 44 2005; and Van Damme and Vrelust 1999. See reference section for complete citations.

flooded and moved to another location very soon after coating application. It has been reported that repair procedures using cofferdams can eliminate the need for extensive diving activity and dramatically reduce costs and improve results of sheet pile repairs near and below the waterline (Voight 2001). This method of repair has not previously been demonstrated and evaluated on a DoD marine structure, so neither DoD personnel nor contractors have experience with it. Project designers and estimators lack historical data for evaluating economic and technical benefits of this technology in comparison to traditional methods of sheet pile wall preservation and repair.

The port of Naha, Okinawa, operated by Torii Station, U. S. Army Garrison Japan, was constructed largely of unpainted sheet pile in the 1950s. Many areas are severely damaged by corrosion and offer excellent conditions for demonstrating in situ repair of steel sheet pile using a movable cofferdam and a high-performance coating.

## **1.2 Objective**

The objectives of this project were to demonstrate and validate the performance of

- a movable limpet cofferdam to efficiently provide a dry subsurface environment for maintenance workers on the face of sheet piles severely degraded by corrosion, and
- an advanced epoxy coating system formulated for coating sheet pile to prevent all forms of corrosion, including ALWC.

During the course of the project, several secondary objectives emerged to address the complexities of feasibility assessment, costing, and scoping the rehabilitation and effective coating of large sheet pile structures. These included development of the methods listed below:

- Effective recommendations for evaluating the structural condition and corrosion activity affecting submerged sheet pile structures
- Methods for feasibility and economic analysis of prospective sheet pile projects to determine whether application of limpet cofferdam technology and select coating systems could significantly reduce infrastructure life-cycle costs as compared to other methods, including sheet pile replacement

- Recommendations for thorough initial site assessment, including tests to identify any root causes of ALWC and microbial-influenced corrosion (MIC)

### **1.3 Approach**

A section of extremely corroded sheet piling supporting a dock at Naha Port, Okinawa was selected as the test site. A working procedure was developed around the use of a commercially available limpet cofferdam for dewatering areas of sheet pile below the waterline. The cofferdam provided a dry working platform. After cleaning and initial surface preparation, the contracted work team determined the best method to repair the structure. Following repairs, an inspector made a visual assessment; collected physical measurements, and recorded photographic evidence of the condition of the sheet pile wall. The inspection included a bacteriological field investigation. Following final surface preparation and inspection, the contractor coated the sheet pile wall with a single-coating, high-build amine epoxy coating known to be effective against ALWC and able to cure under water.

Surface preparation was closely evaluated given its critical importance to coating performance. Surfaces were thoroughly cleaned of salts, corrosion products, and all other residues prior to coating application. Film thickness measurements were recorded and test panels were prepared for exposure at the waterline. These panels were evaluated and retrieved at 6 and 12 months after installation. Cost data was recorded for life-cycle cost analysis and return on investment (ROI) calculations.

### **1.4 Metrics**

The metrics used to assess the performance of the demonstrated systems were as follows:

1. Determine the capability of the cofferdam structure to provide a dry working environment in locations normally under water on the sheet pile.
2. Assess the benefits for using the cofferdam structure compared to conventional underwater repair methods applied by divers.
3. Confirm any ALWC activity and assess the ability of the demonstrated coating to prevent or prevent further steel corrosion where applied.

The industry codes, standards, and test methods used to evaluate the quality of work performed are summarized below

Structural inspections conformed to the following standards:

Specification	Description
ASTM E797	Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
ASTM D 610	Standard Test Method for Evaluating Degree of Rusting on Painted Steel

Weld repairs and procedures conformed to the following specifications:

Specification	Description
ASTM A242/A242M	High-Strength Low-Alloy Structural Steel
AWS D1.1	Structural Welding Code – Steel
AWS Z49.1	Safety in Welding and Cutting and Allied Processes

Surface preparation and coating conformed to the manufacturer's specifications for coating application, which reference the following standards:

Specification	Description
ASTM D4417	Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel, Method B
ASTM D1186	Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base
ASTM D4541	Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
ISO 8502-3	Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness – Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)
ISO 8502-4	Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness – Part 4: Guidance on the estimation of the probability of condensation prior to paint application

Specification	Description
ISO 8502-6	Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness – Part 6: Extraction of soluble contaminants for analysis – The Bresle method
ISO 8502-9	Preparation of steel substrates before application of paints and related products – Tests for the assessment of surface cleanliness – Part 9: Field method for the conductometric determination of water-soluble salts
ISO 8503-2	Preparation of steel substrates before application of paints and related products – Surface roughness characteristics of blast-cleaned steel substrates – Part 2: Method for the grading of surface profile of abrasive blast-cleaned steel – Comparator procedure
ISO 19840	Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Measurement of, and acceptance criteria for, the thickness of dry films on rough surfaces
SSPC-AB 1	Abrasive Specification No. 1 for Mineral and Slag Abrasives
SSPC-VIS 1-89	Guide To Visual Standard for Abrasive Blast Cleaned Steel (Standard Reference Photographs)
SSPC-SP 2	Surface Preparation Specification No. 2 for Hand Tool Cleaning
SSPC-SP 3	Surface Preparation Specification No. 3 for Power Tool Cleaning
SSPC-SP 6/NACE No. 3	Joint Surface Preparation Standard for Commercial Blast Cleaning
SSPC-SP 10/NACE No. 2	Joint Surface Preparation Standard for Near-White Blast Cleaning

## 2 Technical Investigation

### 2.1 Technology overview

#### 2.1.1 Limpet cofferdam technology

The limpet cofferdam is a highly specialized technology in terms of system design and requirements for safe and effective operation. In basic terms, it is an open-top, multistory enclosure designed to be rapidly attached to the face of sheet pile structure and pumped dry to provide a safe workspace for structural maintenance and repair of corrosion damage. Specifically, the limpet cofferdam provides dry access to structural surfaces below the low-water level.

The term *limpet* used for this equipment refers to aquatic gastropods that attach themselves to underwater surfaces using suction to create a pressure drop between their bodies and the objects they cling to. A critical design element of the limpet cofferdam is the sealing technology. In the current project, the selected cofferdam incorporated sealing technology covered by U.S. Patent 5,292,206 (Sonck and Van Draege 1994). After the limpet cofferdam is hoisted down into the water with its seals in contact with the submerged sheet pile structure, the interior of the device is pumped dry and the exterior water pressure pushes the compressible seals tightly against the piles. In this way, the pressure drop “adheres” the limpet cofferdam to the structure without any interlocking mechanical attachment necessary.

Limpets\* are normally manufactured and operated by contracting firms specializing in this type of work. A dry working environment is possible throughout the tidal range and down to the specified depth for which the cofferdam is designed. An economy of scale per unit length of sheet pile wall can be realized on larger projects. However, limpet technology comes with both advantages and disadvantages. Advantages include the following points, as listed below:

- Provides excellent access to critical areas of piles irrespective of tide and depth.
- A standard workshop environment is provided.

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\* In this report, the term “limpet” is often used for brevity in reference to the limpet cofferdam.

- True structural condition can be directly perceived and assessed without the encumbrances of diving equipment.
- Inspection and repairs can be carried out efficiently and concurrently.
- Sequential repositioning and dewatering of the limpet can be accomplished in 30 minutes or less in most cases.

There are several intrinsic barriers associated with the initiation of a project involving the use of a limpet to repair submerged structures. These include

- limited cost data and contractor experience with the technology in the United States
- lack of source planning documents for design engineers
- lack of awareness of this method of work among engineers and consultants.

Special skills required to apply limpet technology include those listed below:

- Assemble and deploy the limpet with little or no modification within three days.
- Seal the limpet against piling without the use of divers within 30 minutes.
- Seal all leaks from the structure into the limpet watertight.

Onsite personnel with requisite limpet technical and application experience provided novice users with the necessary training.

In addition to providing a dry, safe working area below the waterline, the limpet also serves as a containment enclosure that protects the nearby environment from debris and emissions produced during work. The limpet shown in Figure 1 was selected for the demonstration. Its product specifications cover safety, design features, structure, method and materials for assembly, outfitting, stability, and operational efficiency. A third-party engineering firm certified the limpet's structural integrity and suitability for purpose. The limpet was shipped with all necessary auxiliary equipment in two standard shipping containers.

Figure 1. The Acotec Pacific Flyer limpet cofferdam selected for the demonstration.



### 2.1.2 Selected coating

A 24 mil ( $600\mu$ ) coating of high-performance marine epoxy is an effective method of stopping ALWC. Such a coating has an expected service life of 29 years. The use of a single-coat, high-build coating that can cure underwater reduces time, labor, and materials required for application and curing as compared with a standard three-coat system. This project used a modified amine epoxy coating meeting the requirements for the application.

The amine epoxy coating system selected for this project is a 100% solids, two-component coating system. It contains no coal tar pitch, but its intended use overlaps that of the coal tar epoxy formulations traditionally used by the U.S. Army Corps of Engineers (USACE) for this type of application. It has high corrosion and abrasion resistance and is formulated specifically for protecting marine steel structures exposed to severe corrosion environments and ALWC. Data sheets for the selected coating materials are found in Appendix A. Performance features include the following:

- Excellent chemical, abrasion and impact resistance
- Cures at low temperatures
- Self-priming, single-coat system

- Standard spray equipment can apply a single coat up to 40 mils
- Cures underwater and requires no dry cure time before immersion
- Contains 100 percent solids and no volatile solvents
- Safe to marine life during and after cure, as confirmed by independent toxicology reports
- Available in compatible brush-applied and putty variants for stripe coating and filling voids
- Compatible with impressed-current cathodic protection systems

### 2.1.3 Site description

The demonstration sheet pile wall is located at Port Naha, Okinawa, Japan (Figure 2). The condition of the piling and the extent of surface cleaning and repairs required were unknown at the onset of the project. Similarly, estimating the cost and time requirements to perform the work were difficult before deployment of the cofferdam. Cleaning and repairs significantly contributed to project duration and cost.

The hot-rolled structural steel sheet piles were installed in 1950s. The sheet pile was manufactured in Japan. Metallurgical reports were not available. No corrosion-prevention methods were previously applied.

Figure 2. Sheet pile wall at Port Naha, Okinawa, Japan.



Earlier methods to repair the sheet pile walls included the addition of steel plates and concrete (Figure 3). Noncoated steel plating was bolted over damaged sections, but over time those too corroded heavily, lost material thickness, and perforated.

Figure 3. Earlier repairs to sheet pile wall.



The specific section of piling selected for the demonstration met the following minimum criteria for work execution:

- Adequate access to the site location (either from shore or water)
- Sufficient and secure area for assembling equipment and staging material
- Available fresh water for rinsing salts and wet blasting operations
- Sufficient overhead clearance for transport and lifting operations
- Adequate load bearing capacity for equipment along the sheet pile wall for shore access

#### **2.1.4 Health and safety**

No safety and occupational health standards refer specifically to portable limpet cofferdams, but portions of two documents have applicable requirements: (1) Code of Federal Regulations (CFR), 29 CFR Chapter XVII, Part 1926; and (2) Engineer Manual (EM) 385-1-1 (USACE 2014). The manufacturer of the cofferdam provided a comprehensive health and safety manual to the project team.

### **2.1.5 Environmental compliance**

Discharge of pollutants into the port is prohibited. The cofferdam served as the primary containment enclosure for pollutants and debris such as corrosion products, spent blast media, and airborne particulate matter produced during

- abrasive blasting and other surface-preparation operations
- cleaning of steel surfaces on the structure in preparation for coating
- debris removal and collection
- coating application.

The containment protocols included a method to move debris from the enclosure to a central location for environmental-compliant removal.

## **2.2 Field work**

The contractor deployed and dewatered the limpet cofferdam for dry access to submerged areas of the sheet pile wall. After initial cleaning and surface preparation, the contracting team determined the best method to repair the structure. Following inspection, repairs, and final surface preparation, the contractor coated the sheet pile wall with a high performance marine epoxy. High-build barrier epoxy coatings are proven effective against accelerated low-water corrosion (ALWC) when applied on properly prepared steel. The project plan included two follow-up inspections at 6 and 12 months after coating application.

### **2.2.1 Equipment**

Equipment and labor requirements vary according to site location and access. Cofferdam deployment typically requires equipment and services as described below.

#### *2.2.1.1 Heavy equipment*

A 60 ton (55 metric ton) hydraulic crane was used to assemble and deploy the cofferdam from the shore. A forklift was required for material handling.

### 2.2.1.2 *Small equipment*

The following small equipment and accessories were used in the installation:

- Electric power generator
- Air compressor
- Abrasive blasting pot
- Air pollution control equipment
- Welding machines
- High-pressure airless paint sprayer—5,000 psi (360 bar) and 2.4 gpm (9 liters/min), 60:1 pump ratio, and Wagner 560 spray gun or similar
- High-pressure washer (4,350 psi [300 bar]), and
- Freshwater tank

Two platforms were used for work performed above the waterline.

### 2.2.1.3 *Secure storage areas*

Secure storage was provided for the following items:

- onsite office and sanitary facilities
- two standard 40 ft (12 m) shipping containers
- two 12 cu yd (9 m<sup>3</sup>) waste disposal containers for nonhazardous waste
- area for hazardous material storage.

### 2.2.1.4 *Tools*

Common tools needed for surface preparation, limpet assembly, and typical jobsite tasks included those listed below:

- Power cleaning devices such as pneumatic chipping hammers, wire brushes, grinders, rotary peening tools, needle guns, etc.
- Power tools for assembling the limpet, impact wrenches, etc.
- Hand tools for typical mechanical, carpentry, and electrical work.

### 2.2.1.5 *Special materials*

The project required various special materials for repairs and in-place coating, including

- rapid-cure cement

- sprayable amine epoxy coating with compatible putty and brushable variants
- tools and materials for sealing wet holes
- steel plates for reinforcing thin steel.

#### 2.2.1.6 *Consumables*

##### Consumables included

- fuel
- cleaning solvents
- abrasive blast media
- freshwater.

#### **2.2.2 Required contractor services and capabilities**

The task order required contractor services with the capabilities outlined in the subsections below.

##### 2.2.2.1 *Competent person*

Deployment of a prefabricated limpet requires supervision by a “competent person,” usually a representative of the manufacturer. If a competent person is not explicitly required on a given project, the design engineer should consider adding this requirement.

This person must be able to demonstrate competencies related to limpet cofferdam design, assembly, deployment, and operation, as listed below:

- Training, experience, and knowledge of design, assembly, deployment, and work operations of a limpet
- Proper use of personal protection equipment (PPE)
- Ability to detect
  - conditions that could result in structural failure
  - failure or misuse of PPE
  - hazardous atmospheres
  - other hazards associated with working from a limpet
- Authority to take prompt corrective measures to eliminate existing and predictable hazards and to stop work when necessary

### 2.2.2.2 *Welding services*

Welding services were provided to meet the following criteria:

- Certification by American Welding Society (AWS) or approved equivalent
- Diesel-powered portable direct current (DC) welder, 225–300 amp
- Cutting and arc welding tools and accessories.

All wet holes were sealed and patch welded before surface preparation for coating.

Reinforcing (doubling) plates were welded over sections where steel thickness was less than 50% of original, or as directed by the agency.

Doubling plates had to match the original contour of the sheet piling and extend at least 8 in. over steel with thickness greater than 70% of the original steel thickness, or as directed by the agency. The project used 0.25 inch (6 mm) weathering structural steel in conformance with ASTM A242/A242M.

### 2.2.2.3 *Structural steel coating services*

Surface preparation and quality control were performed in accordance with the coating manufacturer's instructions, which consisted of the following points:

- Hydroblast to remove marine growth and loose corrosion products.
- Use manual and power tool cleaning methods to meet SSPC-SP 3.
- Abrasive blast to SSPC-SP 10 (SSI-Sa2 ½, or NACE #2), producing a 2–3 mil (50–75 µ) surface profile.
- Use two-part epoxy coating, mixed per the manufacturer's directions.
- Apply coating with high-pressure airless spraying equipment.

PPE was provided to protect worker health during coating operations.

### 2.2.2.4 *Coating inspector*

The coating manufacturer provided inspection services.

### 2.2.3 Mobilization

The limpet cofferdam and all auxiliary equipment were delivered in two 40-foot shipping containers (Figure 4 and Figure 5). The staging area for the limpet cofferdam was approximately 130 x 65 ft (40 x 20 m) (Figure 6).

Figure 4. Limpet cofferdam arriving at site in shipping containers.



Figure 5. Unloading limpet cofferdam from containers.



Figure 6. Staging area for the limpet cofferdam.



The contractor was able to assemble the limpet in 2 days (Figure 7). The contractor did not have to make any modifications. The limpet satisfied all environmental and safety regulations. Initial deployment and safety training began on the third day after the equipment arrived.

Figure 7. Assembling the limpet cofferdam.



#### 2.2.4 Working platforms

In order to organize the work as efficiently as possible, the contractor executed work from several platforms. The atmospheric zone of the standard

sheet pile (SSP) directly under the capping beam was clearly visible and severely corroded. The condition of the steel under water was unknown.

The contractor deployed two swing platforms for overwater work and the one limpet cofferdam for underwater work. The platforms and cofferdam are shown in Figure 8 and Figure 9. The underwater part of the work from the cofferdam went smoothly due to conditions inside the cofferdam being highly suitable for the work (i.e., lighting, shielding from the elements, floor elevation). The cofferdam was dewatered down to 15 ft (4.6 meters) below the concrete cap.

Figure 8. Overwater working platforms.



Figure 9. Overwater platforms and limpet cofferdam.



### **2.2.5 Sheet pile wall cleaning inspection**

The team had to remove thick layers of amorphous rust and marine fouling. The work was time-consuming and labor-intensive. The 4,350 psi (300 bar) pressure washer was not powerful enough to remove the thick solid layers, so mechanical impact was required. Workers used hammers and pneumatic tools to remove thick layers of corrosion products as shown in Figure 10 and Figure 11. All debris was collected in the sump of the cofferdam.

### **2.2.6 Sheet pile wall repairs**

Prior to weld repairs, all leaks were sealed watertight. Steel reinforcing plates were welded over any unsound metal. Patch plates were welded over any holes below the waterline. After welding, voids behind the reinforcing plates were injected and filled with cement grout or epoxy resin

Figure 10. Manual removal of corrosion products.



Figure 11. Pneumatic removal of corrosion products.



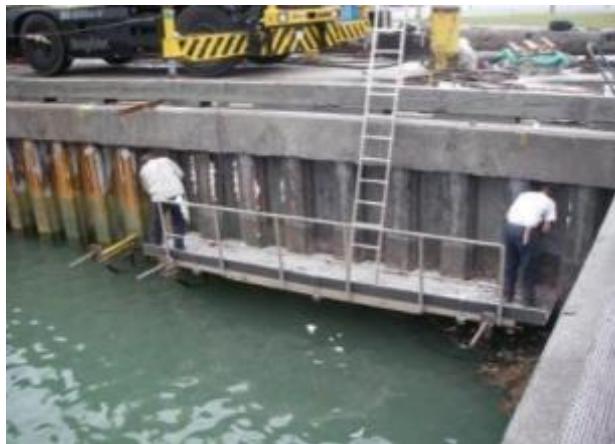
#### 2.2.6.1 Sheet pile wall repairs above waterline (splash zone to concrete cap)

The contractor installed two work platforms at low tide. The platform edge was designed with a profile to match that of the pilings (see Figure 12) in order to contain debris created during repair and surface preparation. Brackets were welded to the out-pans of the piles to support the platforms, as shown in Figure 13.

Figure 12. Platform for overwater work.



Figure 13. Workers repairing piles overwater.



After manual and mechanical removal of loose debris and corrosion products, workers used abrasive blasting equipment to remove the more tightly adhering corrosion products. Inspection after the initial sheet pile wall cleaning revealed extensive perforations and loss of steel in a 3 ft (1.0 m) band above the waterline. The condition is shown in Figure 14.

Figure 14. Corrosion in the atmospheric zone.



Each pile was heavily corroded and there were perforations in the area between the splash zone and the underside of the concrete capping beam. All of the holes were situated at the corners and webs of the out-pans in a band of approximately 2.6 ft (0.8 m) under the capping beam. The steel of the in-pan was only perforated in a few places, and remaining steel was on average about half the original thickness, or approximately 0.4 in. (10 mm). The remaining steel was thick enough to dry weld reinforcing plates to it. Small isolated holes were plugged with a special cement suitable for the purpose.

Much backfill had fallen out. Larger stones remained in place. The scope of work did not include refilling voids behind the piles, but the contractor injected polyurethane foam in lieu of replacing backfill (Figure 15). After the perforations were filled, the contractor filled the surface of the piles with proprietary cement, as shown in Figure 16. At the conclusion of this work, the piles (Figure 17) were watertight.

Figure 15. Polyurethane injection into voids behind piles above the waterline.



Figure 16. Application of proprietary cement to surface voids.



Figure 17. Remodeled corners prior to attaching doubling plates.



Either non-shrink grout or epoxy resin material was injected between the doubling plate and the pile, which provided structural reinforcement. A close fit between the doubling plates and piles reduced the amount of injection material and associated costs. Appendix B has diagrams depicting sheet pile wall repairs above the waterline.

The contractor prepared 100 plates 0.25 in. (6 mm) thick and 3.3 ft (1 m) high to reconstruct 50 piles. Figure 18 shows the material staged at the site. A local metal shop rolled the plates to fit the original pile as closely as possible. A 3/8 in. (10 mm) hole was drilled in each plate to allow injection of either non-shrink cement grout or epoxy resin in the gap between old and new steel, shown in Figure 19. This was the reason why the perforated piles needed to be made liquid-tight with cement grout or epoxy. Otherwise, the material injected between the old and new steel would be lost behind the old steel.

Figure 18. Doubling plates.



Figure 19. Drilling injection hole.



Two workers installed and tack-welded the plates with use of an inverter welding set (welding rods), as shown in Figure 20. A third person finished the welding with a semiautomatic welder using Lincoln Intershield 1.4 mm wire (Figure 21).

Figure 20. Tack welding plates.



Figure 21. Continuous welding of plates.



After welding, the contractor injected the amine epoxy filler material into any voids between old steel and the new doubling plates. The material protected the new steel from the back side. A spray hose was screwed into the 3/8 in. (9.5 mm) hole at the top of each plate, and epoxy was pumped in until it discharged from the hole at the opposite side of the out-pan. The holes were plugged with 3/8 in. (9.5 mm) bolts.

Following the repairs, surfaces were prepared for painting by abrasive blasting. The limpet cofferdam served as a primary containment enclosure. Forced ventilation and air pollution control equipment maintained emissions within published standards.

#### 2.2.6.2 Work below the waterline

##### 2.2.6.2.1 Cofferdam deployment

The contractor used a 60-ton (55 metric ton) hydraulic crane from the shore to hoist and position the cofferdam. If shore access had not been feasible, the contractor could have used either a crane or gantry system mounted on a barge.

Before deploying the cofferdam, the contractor scraped the sheet pile wall with an excavator. After scraping the out-pans with a flat edge bucket, the contractor welded a blade on the bucket that matched the contour of the in-pans. This method reduced the time needed to clean the sheet pile and removed barnacles that damage and interfere with the cofferdam seals.

##### 2.2.6.2.2 Sheet pile wall repairs below waterline

After the limpet cofferdam was dewatered, water from the backside of the piling immediately spouted from larger holes. Numerous holes of various sizes and shapes were found throughout the sheet piles. Only after initial cleaning did pinholes, such as those in Figure 22 appear. Water leaked out of some interlocks and tie-rod anchor plates. All wet holes and leaks were sealed watertight before repair plates were welded in place.

All leaks had to be sealed watertight before welding repair plates. The contractor attempted various techniques including plugging with various materials, foam injection, and quick-setting cement. These methods were time consuming and did not always provide satisfactory results. More innovative techniques eventually resulted in additional increases in production and ultimate surface dryness.

Figure 22. Platform at -11.5 ft (-3.5 m) below surface a (left), and pinhole leaks that appeared after initial surface preparation.



Two-inch (50 mm) diameter holes were found at -8 to -11 ft (-2.5 m and -3.5 m). The location of most holes was on the out-pan of each pile, as shown in Figure 23.

Figure 23. Example hole on out-pan.



These holes were likely made at the time of construction for tie rods. Subsequently, the tie rods were installed on the in-pans, and the holes were left open. Only a few perforations actually caused by corrosion were identified under the waterline. These holes were patch-welded with 8 x 8 x 0.25 in. plates (200 x 200 x 6 mm), as shown in Figure 24.

Figure 24. Example of a patch weld.



## 2.2.7 Surface preparation and cleaning

Surface preparation is the primary factor that determines coating effectiveness. After repairs, the contractor cleaned steel surfaces to at least SSPC-SP 10 (SSI-Sa2 ½, or NACE #2 (near white metal) and a surface profile of at least 2.0 mil to 3.0 mil (50 µ to 75 µ). Cleaning must produce surfaces that are structurally sound, free of dirt, dust, abrasives, grease, oil, paint, etc.

High-pressure washing with tap water was used to remove salts. Adequate forced ventilation provided dust control. Air pressure and clean brushes were used to remove surface dust. The contractor measured soluble salts and dust on prepared steel surfaces to ensure that the concentrations of these contaminants are less than the levels allowed by the coating manufacturer.

Maximum allowable chloride concentrations and soluble salts were set by the contractor at 60 mg/m<sup>2</sup> and 90 mg/m<sup>2</sup>, respectively. The method for determining these values is described in ISO 8502-6 and ISO 8502-9, respectively. Admissible amount of dust was quality degree 3, class 2 per ISO 8502-3. A subjective absorbency test using cigarette paper was normally sufficient for evaluating surface dryness. A surface temperature 5 °F (2 °C) above the prevailing dew point was normally sufficient to prevent condensation from forming.

### 2.2.8 Coating application

Prior to coating application, deep pits, voids and interlocks were filled with the amine epoxy putty, a compatible variant of the demonstrated coating. Deep pits can be seen in (Figure 25). If these are not filled, an air pocket may form beneath the coating and may cause coating failure at the pit (Figure 26). The interlocks between piles are caulked. To better ensure uniform material thickness on difficult-to-coat areas, the contractor coated all sharp edges with Humidur BAML, the brush-applied variant of the amine epoxy coating system, and used the putty variant (Humidur P) to fill gaps and deep surface irregularities (Figure 27) and Figure 28).

Figure 25. Deep pits in surface-prepared bare steel plating.



Figure 26. Holiday in coating formed over deep surface pit.



Figure 27. Z pile interlocks treated with Humidur putty and brush-applied variants.



Figure 28. Brush application of Humidur BAML on sharp edges before spray coating.



Painters have better control over the spray pattern when the coating temperature is constant at the spray nozzle. The product used in this demonstration has the best spray performance when the temperature is 100 °F (38 °C) at the nozzle. To achieve optimum spray performance at lower ambient temperatures, the coating was heated in a 104 °F (40 °C) bath. Spray hoses were wrapped with heating cables and insulated.

The contractor applied the epoxy coating in accordance with the manufacturer's instructions. The nominal recommended coating thickness is 16 mils (400  $\mu$ ) on new steel. On heavily pitted steel, a nominal thickness of 24 mils (600 $\mu$ ) is recommended to adequately cover the peaks and valleys of the rough surface. Pits, interlocks, and repair plates increase the actual surface area to be coated. Therefore, the actual coverage rates can be lower by more than 50% of the manufacturer's nominal coverage rate. After application, the inspector visually checked for holidays and measured wet film thickness.

This two-component epoxy coating product can cure underwater. Immediately after application of the coating is completed, the contractor can flood the cofferdam, hoist it out of the water, and repeat the sequence of work

further along the sheet pile wall. Figure 29 shows the sheet pile wall before the task order (left) and after completion of the work (right).

Figure 29. Sheet pile wall before (left) and after renovation (right).



## 2.2.9 Containment

The cofferdam serves as a primary containment enclosure. As noted in section 2.1.1. above, it helps to prevent visible emissions or releases of spent materials, dust, or other debris into the environment. All debris that falls to the bottom of the cofferdam can be collected for proper disposal. Each day after work was complete, the cofferdam was slowly refilled with water. The spent blast media and removed coatings and rust became packed as a wet mass at the bottom of the enclosure. The cofferdam was then hoisted slowly from the water to avoid washing any of the debris away and was parked on the dock to finish draining overnight. Figure 30 shows how the cofferdam was hoisted over the waste container and emptied manually with shovels and brooms.

Figure 30. Emptying waste material collected in cofferdam.



#### 2.2.10 Installation of reference panels

In order to monitor and test coating performance over time, the contractor installed 24 panels on the underwater face of the sheet pile wall for exposure. Figure 31 shows the contractor installing the reference panels as work was completed for one section of the sheet pile wall.

Figure 31. Installation of reference panels.



The reference panels were approximately 3 x 9 in. (8 x 23 cm) and fabricated of mild steel. Twelve panels were coated with the amine epoxy coating using the same process that was used to coat the sheet pile on the seawall. The other twelve were installed untreated.

The contractor placed one coated and one untreated panel at level –3.2 ft and –8 ft (–1.0 m and –2.5 m) of the in-pan between the following piles: 0–1, 7–8, 15–16, 31–32, 39–40, and 47–48. These locations are where corrosion was found to be most aggressive. Figure 32 shows treated and untreated panels side by side.

Figure 32. Treated and untreated panels installed on sheet pile wall.



## 2.3 Performance monitoring

### 2.3.1 Limpet cofferdam performance

Efficient sealing is a critical design element of the limpet cofferdam. The patented sealing system proved highly effective at water depths over 10 ft (3 m). With one exception, deployment and dewatering occurred in less than 30 minutes, without the use of divers.

The exception was due to an unforeseen condition; a sheet pile had been driven out of its interlock with an adjacent pile. The limpet was unable to seal the cofferdam between piles 22 and 26. A diving inspection revealed that the interlock between piles 24 and 25 was open from –12 ft (–3.5 m) down to the mud bottom. Pile 24 was standing out from the face of the

wall. The opening between the piles at the mud line was approximately 24 in. (60 cm). The backfill had washed out. The gap provided a direct connection between the seawater and the inside of the cofferdam. The gap was plugged temporarily under water until the contractor could dewater the limpet cofferdam. The part of the gap that extended into the cofferdam was plugged with cement. The defect originated at the time of construction and was probably never noticed. Because of the low visibility under water, it was not possible to document the defect with pictures or video.

### 2.3.2 Steel thickness measurements

Prior to coating, the inspector performed ultrasonic thickness measurements of the piles. The test instrument was a calibrated Krautkrämer DM4E. Before the work started, all sheet piles were numbered and marked for reporting and monitoring purposes. At each of the 50 sheet piles, 42 measurements were taken at four surfaces: in-pan, out-pan and webs between level –3.25 and –13 ft (–1.0 m and –4.0 m) below the concrete cap.

Each of the 42 measurements was the average of four measurements in a 2 in. (5 cm) diameter area. In total, 2,100 average steel thicknesses were recorded out of 8,400 measurements taken (Figure 33). Locations of deep pits were also identified and measured using the gauge shown in (Figure 34).

Figure 33. Measuring steel thickness.



Figure 34. Measuring pit depth.



### 2.3.3 Bacteriological field investigation

A bacteriological field investigation was conducted using a suite of Biological Activity Reaction Tests (BART<sup>\*</sup>) described in Appendix C. This test identifies the presence and type of various bacteria species. In this project, the tests were selected and performed to detect the presence of various bacteria linked to MIC in steel corrosion products and biofilms. The results of these tests indicate the presence of microbial life that can promote MIC and contribute to degradation by ALWC.

### 2.3.4 Surface preparation coating

The coating manufacturer conducted quality-control tests of the surface preparation in accordance with coating manufacturer's specifications.

## 2.4 Follow-up inspections

### 2.4.1 Reference panels

After 6 months, the contractor removed three treated and three untreated panels for inspection. After 11 months, the contractor removed and inspected six more panels. The remaining panels remain on the sheet pile wall for long-term exposure analysis. The inspection included photographs and evaluation per ASTM D 610, ASTM D 714, and ASTM E 1645. Results are discussed in Chapter 3, section 3.1.

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\* BART is a trademark of LaMotte Co., Chestertown, MD.

## 2.4.2 Adhesion test

The inspector conducted one adhesion test at -6.5 ft (-2.0 m) on pile number 46 with the pull-off adhesion tester shown in Figure 35. The coating was applied on 21 November 2008 and tested on 4 December 2008. The dolly of the tester showed glue failure with a small amount of green pigment from the surface of the coating because the amine epoxy had not fully cured when tested. However, the coating did not detach. Full cure time for amine epoxy coating is 3 weeks at 68 °F (20 °C). The results shown in Figure 35 and Table 1 indicate very good coating adhesion.

Figure 35. Adhesion test.



Table 1. Adhesion test results, -2.0 m at Pile 46.

Dolly	Location	Reading psi (MPa)	Failure
1	Out-pan	1740 (12.0)	100% glue
2	Out-pan	2045 (14.1)	100% glue
3	In-pan	1567 (10.8)	100% glue

## 2.5 Warranty

The manufacturer warrants performance of this coating for 10 years.

## 3 Discussion

### 3.1 Results

#### 3.1.1 Steel thickness

Based on typical specifications for this type of sheet piling, original estimated steel thickness at the in-pans and out-pans was 0.79 in. (20 mm). Original estimated steel thickness at the webs was 0.59 in. (15 mm). Residual steel thicknesses were measured and sorted into three categories:

- Steel thickness more than 0.3 in. (8 mm) (1/3 of original thickness)
- Steel thickness 0.24–0.3 in. (6–8 mm)
- Steel thickness less than 0.24 in. (6 mm) and deeply pitted

Pit impact on residual steel thickness was accounted for by subtracting pit depths that were measured using the gauge shown previously in Figure 34, from ultrasonic thickness measurements of the surrounding steel.

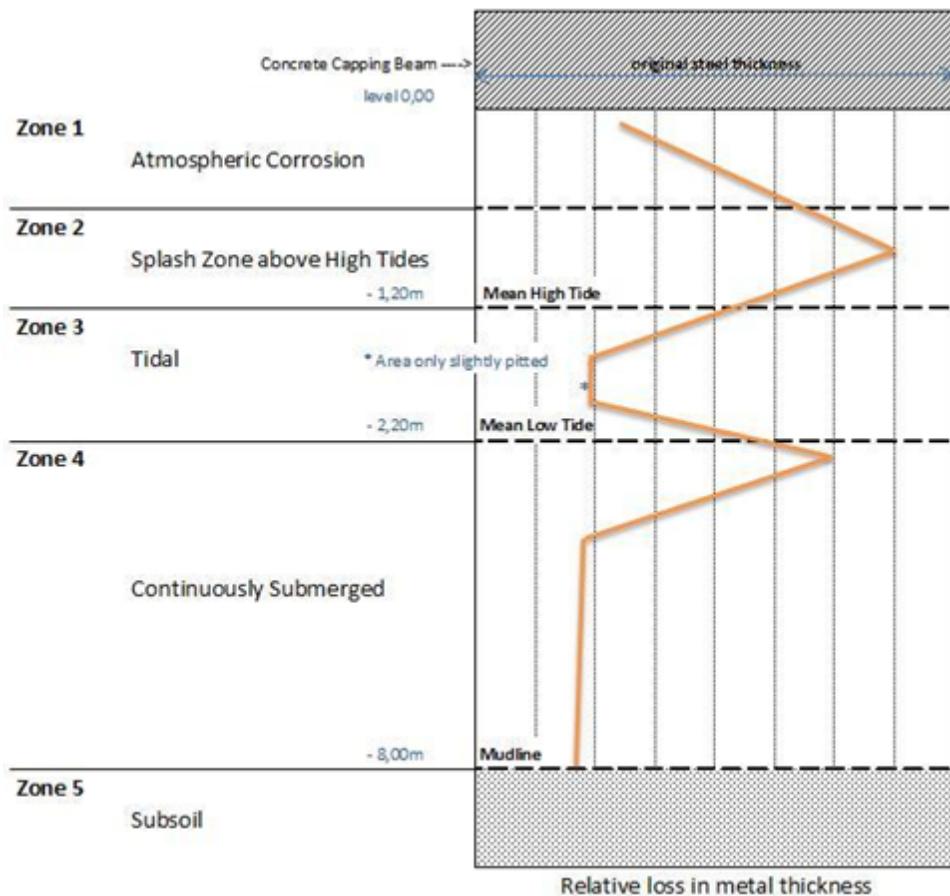
#### 3.1.1 Corrosion rates

Thickness measurements showed the average sheet pile thickness to be approximately 0.43 in (11 mm), with a 20% variance. This result corresponds to an approximately 50% loss of the original steel having occurred uniformly. In terms of sheet pile life cycle, starting at time zero, the uniform loss of steel corresponds to a minimum of 8 mil (0.2 mm) per year over a 50 year exposure. However, the data suggest that material loss occurred at a rate much lower than 8 mil per year in earlier years, after which the corrosion rate dramatically increased due to ALWC.

#### 3.1.2 Corrosion profile

Maritime structure design has traditionally considered corrosion conditions in distinct vertical zones in relation to the sea. These zones, and their typical corrosion conditions and rates, are described below and illustrated in Figure 36. The loss of steel from –3.25 to –8 ft (–1.00 m to –4.00 m) was between 23% and 60%. Flanges on the in-pans and out-pans showed 15% – 25% more loss of steel than the webs. Pitting was prevalent from –3.25 to –1 ft (–1.00 m to –2.50 m). On piles 13–26 and piles 32–50, pitting corrosion extended to –8ft (–4.0 m).

Figure 36. Typical corrosion profile of steel pilings in ocean tidal water.



### 3.1.3 Atmospheric zone

The atmospheric zone extends from approximately 0 to  $-32$  in. (0.0 m to  $-0.8$  m). The deterioration of the piles was clearly visible. Thick rust scales were found on all surfaces of the profile (webs and flanges). Between  $-2$  and  $-32$  in. ( $-0.060$  m and  $-0.80$  m), steel was completely corroded away on the water-side corners. Deep localized pitting was observed on the in-pans. Piles were remodeled with cement and reconstructed with doubling plates of 1 m high.

### 3.1.4 Splash zone

The splash zone extends from approximately  $-32$  in. to  $-4$  ft ( $-0.8$  to  $-1.2$  m) (mean high tide). The splash zone had general pitting with very small perforations.

### 3.1.5 Tidal zone

The tidal zone extends from approximately elevations  $-4$  ft ( $-1.2$  m) at mean high water to  $-7.2$  ft ( $-2.2$  m) at mean low water. Prior to cleaning, the region between  $-40$  in and  $-5$  ft ( $-1$  m and  $-1.5$  m) appeared sound. The sheet piles had little marine fouling, as seen in Figure 37. Below  $-5$  ft ( $-1.5$  m) the piles were completely covered with shells and vegetation prior to being scraped (Figure 38).

Figure 37. Tidal zone below  $-5$  ft ( $-1.5$  m).



Figure 38. Tidal zone below –5 ft (–1.5 m).



Cleaning revealed a thick layer of amorphous rust more than 0.4 in. (10 mm) thick. The thick rust layer was very difficult to remove. Between –5 ft and –6.5 ft (–1.5 m and –2.0 m), the intact steel underneath was only slightly pitted.

### 3.1.6 Low-water zone

The low-water zone extends from approximately –6.5 ft (–2.0 m) to at least –13 ft (–4.0 m). The condition of the sheet pile wall was unknown prior to deployment of the cofferdam. The thick layer of amorphous rust extended from the tidal zone to the low-water zone. Between –6.5 ft and –13 ft (–2.0 m and –4.0 m) the intact steel underneath was heavily pitted. The unusual striations were parallel grooves running at 30 – 45 degrees from the vertical. Some patterns cross each other symmetrically. The striations were likely a sign of MIC.

Bacteriological field investigation showed the presence of the bacteria associated with the corrosion damage. These types of bacteria are known to promote corrosion of iron through reactions leading to the dissolution of corrosion-resistant oxide films (passivation layer) on the metal surface. Pits develop much faster than the general corrosion rate.

### 3.2 Follow-up inspection of treated areas

#### 3.2.1 Inspection after 6 months

##### 3.2.1.1 Sheet pile wall

The contractor inspected the sheet pile wall on 8 June 2009, 6 months after completion of work. Figure 39 shows the general condition of the sheet pile wall and Figure 40 is a closer view.

Figure 39. General condition of sheet pile wall 6 months after renovation.



Figure 40. Closer view of completed work after 6 months.



Below is a summary of inspection results after 6 months:

- Degree of rusting (ASTM D610-08 Grade 10) was less than 0.01% of total surface.
- Degree of blistering (ASTM D714-02, Grade 10) was less than 0.01%.

From level 0 to  $-5$  ft ( $0.0$  m to  $-1.5$  m), some pinholes and minor mechanical damage appeared. From  $-5$  ft to approximately  $-10$  ft ( $-1.5$  m to approximately  $-3.0$  m), no defects were observed. Figure 41 shows examples of pinholes visible after cleaning (left) and a rust stain at Pile 23 (right). Appendix D is the 6-month inspection report.

Figure 41. Two small pinholes (left) and rust stain (right).



### 3.2.1.2 Reference panels

The contractor removed and inspected one treated and one untreated panel from the following locations for a total of six panels: two on pile 8 at elevation  $-8$  ft ( $-2.5$  m); two on pile 16 at elevation  $-40$  in ( $-1.0$  m); one coated panel on pile 32 at elevation  $-8$  ft ( $-2.5$  m) and one uncoated panel on pile 32 at elevation  $-10$  ft ( $-3.0$  m).

Test and evaluation report for these panels is in Appendix E. The panels were in excellent condition and showed no sign of rust or blistering. After field inspection, the panels were sent for laboratory assessment.

### **3.2.2 Inspection after 11 months**

#### **3.2.2.1 Sheet pile wall**

The contractor inspected the sheet pile wall on 6 December 2009, 11 months after completion of work. Below is a summary of inspection results after 11 months.

- Degree of rusting (ASTM D610-08 Grade 10) was less than 0.01% of total surface.
- Degree of blistering (ASTM D714-02, Grade 10) was less than 0.01%.

Appendix F is an evaluation of the coating condition after 11 months. All pinholes and mechanical damage observed during the 6-month inspection have been repaired.

#### **3.2.2.2 Reference panels**

The contractor removed and inspected one treated and one untreated panel from the same three locations (six panels) indicated above in section 3.2.1.2).

The panels were in excellent condition and showed no sign of rust or blistering. After field inspection, the panels were sent to the company's laboratory.

## **3.3 Lessons learned**

Costs for this type of work are a direct function of project duration. The major factors that impacted this project's duration included the sealing efficiency of the limpet and the extent of necessary sheet pile repairs.

The extent of repairs had significant impact on estimated project costs and duration. The condition of the sheet pile wall was difficult to ascertain before deploying the limpet. An accurate method of estimating repair costs was not available until inspectors had access to the limpet. The following conditions were not known until after the project began:

- Extent of the thick, amorphous rust in the tidal and low water zones
- A split between piles 24 and 25 near the mud bottom (see next section)
- Size and location of leaks and holes
- Amount of backfill loss from behind the existing sheet pile wall

### **3.3.1 Limpet sealing process and sheet pile leak repair**

With one exception, deployment and dewatering of the limpet was completed in 30 minutes or less without the use of divers. The exception was a previously unknown problem: a sheet pile had been driven out of its interlock with an adjacent pile. A 24 in. (60 cm) gap between adjacent piles below the waterline had to be repaired and sealed. This situation increased project duration approximately 10 hours and required the use of a dive team.

Some methods used to seal wet holes proved to be time-consuming and initially stalled work progress. The results often allowed some continuing water seepage, which can cause premature coating failure. Leak-sealing methods included plugging holes with various materials such as foam, oakum, quick-setting cements, and fast-curing epoxy. A special cement was used for sealing leaks at tie-rod backing plates, pile interlocks, and small pinholes. As techniques for sealing leaks improved, the time to seal leaks decreased from an average of more than 4 hours per hole to less than 30 minutes per hole. The final result of an effective repair was a completely dry surface.

A unit price for large sheet pile repairs was difficult to establish at the onset of the project. Techniques and costs naturally vary according to steel geometry and location. Repairs at corners and other nonplanar surfaces required more effort than on flat surfaces. Reinforcing plates had to be formed to fit bends in the piles at in-pans and out-pans.

### **3.3.2 Surface cleaning issues**

A 0.4 in. (10 mm) thick layer of amorphous rust was found after work began. Removing the rust layer increased surface preparation time 2–3 hours per pile. The steel beneath this layer was found to be pitted.

This work was fatiguing and had a significant impact on crew productivity. Initial progress was slow. The duration of project work for one setup encompassing four piles took approximately 3 days. Progress accelerated as the crew gained experience, increasing surface cleaning to approximately 2.5 days per setup. An increase in crew size to improve the cleaning rate could not be considered because it was outside the scope of the contract.

In retrospect, progress may have been faster using ultra-high-pressure water blasting 29,000 psi (2,000 bar), but the need for this type of equipment was not foreseen, and it was not available on the island of Okinawa.

### **3.3.3 Coating application**

Pinholes appeared in the coating over areas of severe pitting. Air trapped under the coating expands during the curing process and forms a bubble. When the bubble bursts, coating integrity may be lost. The contractor filled most deep pits and voids with a brushable or a putty variant of the amine epoxy coating, but some pits were missed. These small defects are difficult to detect during coating applications. They were repaired during the 11-month inspection (see Appendix F).

## 4 Economic Analysis

### 4.1 Costs and assumptions

Total project costs for this CPC project are broken down in Table 2, and the costs for the field demonstration and validation are shown in Table 3.

Table 2. Breakdown of total dem/val project costs.

Description	Amount, \$K
Labor	307.3
Contract for Field Demonstration	467.7
Travel	70
Reporting	20
Air Force and Navy participation	10
Total	875

Table 3. Field demonstration costs.

Item	Description	Amount, \$K
1	Labor for project management and execution	24.3
2	Travel for project management and execution	14.9
3	Subcontract for painting and portable cofferdam	428.5
	Total	467.7

Table 4 shows the actual costs of repair, surface preparation, and coating applications for 133 linear feet steel sheet pile wall in bad to poor condition. The \$362,122 total cost does not include fixed costs, including mobilization and demobilization of equipment, which can be disproportionately high for a small job such as the amount of steel rehabilitated in this project. Other costs such as travel and per diem will vary significantly depending on project location.

**Table 4. Breakdown of actual costs of repairs and coating application.**

Description	No. Units	Unit	Unit Cost (\$)	Extension (\$)
Time to complete the work: Labor and equipment to remove amorphous rust and solve an interlock failure.	6	Day	7,724	46,344
Structural repairs: Fit, install, and weld doubling plates 40 x 20 x 1/4 in., bent to fit contour of piling.	50	piles	2,642	132,100
Repair holes below waterline: Seal holes watertight. Fit, install and weld patch plates over wet holes, 8 x 8 x 1/4 in.	88	plates	636	55,968
Final surface preparation, inspection and coating application. Included extra time for scale removal	2900	ft <sup>2</sup>	44.04	127.710
Actual costs				362,122

The contractor also noted that the costs to remove the thick layers of amorphous rust and repairing the complete upper part with doubling plates are almost twice the cost of inspection and coating.

#### **4.1.1 General assumptions**

A stretch of steel sheet pile wall in bad to poor condition measuring 133 linear feet was repaired and coated under this project. The actual cost, not considering mobilization and travel/per diem costs, is approximately \$2,723 per linear foot. Including those costs, the cost per linear foot amounts to \$3,698. In other words, the mobilization and travel costs represented for this dem/val project are approximately \$1,000 per linear foot.

The cost to inspect and coat the same sheet piling in fair condition with minor repairs could be as little as half the costs encountered for this project (\$1849/ft). Table 5 projects the relative cost (where 1 is equivalent to \$1849/ft) to renovate sheet pile walls in various conditions.

Since no actual cost figures for the original installation of the steel piles were available, several assumptions were required to develop the baseline cost for calculating the project. First, the midrange estimate (\$7,750/linear foot) in section 4.3.1 to install new Z piling over 50 feet in length was applied to baseline installation costs. Second, the midrange estimate (15% of installation cost [\$1162.50/linear foot]) from section 4.3.1 was used for

the initial cost of engineering, design, geological surveys, and other professional services. This resulted in baseline cost of \$8912.50 per linear foot.

A 25-year service life is used for both the uncoated steel pilings and for the coating system. The replacement cost in Year 27 is the cost of repairing and coating a structure in fair condition, which is assumed to be \$1850/linear foot (50% of the initial costs of the Port Naha project).

**Table 5. Relative costs to renovate sheet pile walls in various conditions.**

Sheet pile wall Condition	Welding Requirement	Relative Cost	Expected Additional Service Life
Good – Excellent	Minimal	0.9 – 1.4	25 – 50 years
Fair – Good	Minor	1.3 – 1.8	25 – 50 years
Poor – Fair	Moderate	1.8 – 2.0	Please see Section 4.1.4 below
Bad – Poor	Substantial	> 2.0	

#### **4.1.2 Alternative 1 (Baseline Scenario)**

A new 2,000 linear feet long seawall using uncoated steel was installed in Year 2 at a cost of \$8,912.50 per linear foot, for a total cost of \$17,825,000.00. With an estimated service life of 25 years, a new wall would have to be installed in Year 27. Typically, no maintenance or other work would be done on these steel sheet pilings in the interim. These costs are included in the Baseline Costs column of the ROI spreadsheet (Table 6).

#### **4.1.3 Alternative 2 (Demonstrated Technology)**

A 500-foot long sheet pile wall section in bad to poor condition is coated in Year 2 at a cost of \$3,700 per linear foot (two times the base of \$1,850.00 per linear foot for the existing bad to poor condition) for a total cost of \$1,850,000. (\$875,000, the Investment Required, was expended to repair 133 linear feet in Year 1 as a proof of the technology.) A second 500-foot section in poor to fair condition would be coated in Year 3 at a cost of \$1,757,500 (\$3,515 per linear foot times 500 feet). A third 500-foot section in fair to good condition would be coated in Year 4 at a cost of \$1,387,500 (\$2,775 per linear foot times 500 feet). A final 500-foot section in good to excellent would be coated in Year 5 at a cost of \$925,000 (\$1,850 per lin-

ear foot times 500 feet). In each case the coating would increase the expected service life up to 25 years. A recoating cycle would begin again starting in Year 27 through Year 30. However, given the extent of the repairs completed 25 years before, the condition of the sheet piles walls is assumed to be in the fair to good condition for each case. Recoating is, therefore, calculated at \$2,775 per linear foot, for a total of \$1,387,500. All of these costs are included in the New System Costs column in Table 6, below.

## 4.2 Projected return on investment

The ROI for this technology demonstration was computed using methods prescribed by Office of Management and Budget (OMB) Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs* (OMB 1992). Comparing the costs and benefits of the two alternatives, the 30-year ROI after implementing the new technology (Alternative 2) is projected to be 14.70 as shown in Table 6. This ROI, for rehabilitating and extending the service life of 2,000 ft of sheet pile, is considered conservative since the DoD has many miles of uncoated sheet pile walls in service at its waterfront facilities, which could benefit by the application of this technology.

Table 6. ROI calculation for steel pilings in poor condition before repair and coating.

**Return on Investment Calculation**

			<b>Investment Required</b>				<b>875,000</b>
			<b>Return on Investment Ratio</b>	<b>14.70</b>	<b>Percent</b>	<b>1470%</b>	
			<b>Net Present Value of Costs and Benefits/Savings</b>	<b>5,577,815</b>	<b>18,436,398</b>	<b>12,858,583</b>	
A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1							
2	17,825,000		1,850,000		1,615,790	15,568,355	13,952,565
3			1,757,500		1,434,647		-1,434,647
4			1,387,500		1,058,524		-1,058,524
5			925,000		659,525		-659,525
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27	17,825,000		1,387,500		223,249	2,868,043	2,644,794
28			1,387,500		208,680		-208,680
29			1,387,500		195,083		-195,083
30			1,387,500		182,318		-182,318

The original Project Management Plan (PMP) estimated an ROI of 11.85. The higher ROI of 14.70 is due to several factors. The lower initial installation cost estimate (\$8,912.50 versus \$33,835.00 per linear foot) than presumed in the PMP is based on a more realistic assumption for project size—2,000 linear feet of wall versus the 133 liner feet on which the demonstrated technology was used in this CPC project. Also contributing to the increase in the final calculated return is the longer calculated service life of 25 years than the originally service life of 12 years assumed in the PMP.

## 4.3 Supplemental economic and life-cycle cost information

### 4.3.1 Baseline configuration

When annual cost variables can be projected with some accuracy, all alternatives for sheet pile wall construction and repair can be estimated and compared with each other. When one or more variables cannot be projected with accuracy, comparisons can best be drawn against a baseline

configuration that represents a typical sheet pile wall application with known costs and service life. For this project, the baseline condition is a steel sheet pile wall installed with no protective coatings or cathodic protection and no maintenance before the time of repair or replacement. The annual cost of a steel sheet pile wall can be calculated using the following formula:

$$\text{Annual baseline cost} = P [ i * (1+i)^n / (1+i)^n - 1 ] \quad (1)$$

where

P = installation cost, in dollars per linear foot

n = lifetime, in years

i = time value of money at Year 0, in percent

This formula assumes that there will be no salvage value at the end of the structure's functional service life (Kumar and Stephenson 2005).

The initial installation cost is the initial expenditure for the wall, and it should include the material costs, transportation costs, and onsite handling and pile-driving costs. For a sheet pile wall, it is customary to include the cost of anchors, tie rods, and wales as well as excavation and backfilling costs.

Estimates of the cost to install new Z piling over 50 ft in length during the first quarter of 2009 range from \$6,500 to \$ 9,000 per linear foot.\* This is an estimate of installation cost only, excluding mobilization and inspections. Additional costs for engineering, design, geological surveys, and other professional services may range from 10%–20% of the installation cost. The design engineer should also include the additional cost to make civil infrastructure repairs on the land side. For the ROI calculations, the midrange of installation and additional initial costs is used (\$7,750 per linear foot and 15% of installation cost, respectively).

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\* (a) NAVFAC Solicitation N40085, Repairs to W306 and W305 Bulkhead at Naval Station, Norfolk, VA, average of line item 0001H price; (b) Port of Seattle Memorandum dated Jan. 13., 2009; (c), J. Berry, "Unsafe Harbor Restricts Access," *Cape Cod Times*, April. 24, 2009, p. 1(d) NAVFAC Solicitation N6945009R1259, Design and Construction for P999 Warf Alpha Improvements at Naval Station Mayport, FL. Fifty percent of project value is estimated to replace of 900 ft of sheet piling.

#### **4.3.2 Cost evaluation of repair systems to extend sheet pile wall life**

Price data from the open market are not available or sufficient for calculating costs. In the absence of cost data, project design engineers need tools to evaluate the benefit/cost ratio of repair techniques with a limpet coffer-dam in comparison with other methods. A 1967 Naval Facilities Engineering Command (NAVFAC) report includes a method for making comparisons when cost data are not available (Fettig and Jones 1967). The typical service life of steel sheet pile wall in a marine environment is 30–40 years. “The end of lifetime is defined by any one of the following three conditions: (1) collapse or buckling of a significant portion of the sheet pile wall; (2) gross loss of backfill through holes in the sheet pile wall; (3) or frequent and expensive maintenance to keep the sheet pile wall in service” (Fettig and Jones 1967).

A sheet pile wall deteriorates unevenly. The area from slightly below the tidal zone to the splash zone may approach failure while the top and bottom of the sheet pile wall are still serviceable. Steel piling driven below the mud line, which is not corroded, can be a very strong foundation for additional construction. Repair methods that use this noncorroded steel as a basic part of a life-extension system can be applied near the end of the normal service life.

A formula for determining how much can be spent at the end of the normal service life to extend it by some period of years is

$$\begin{aligned} P * [ i * (1+i)^n + y / ((1+i)^n - 1) ] + L * [ 1 / (1+i)^n ] * P * \\ [ i * (1+i)^n / (1+i)^n - 1 ] \leq P [ i * (1+i)^n / (1+i)^n - 1 ] \end{aligned} \quad (2)$$

where L equals maximum investment (dollars per linear foot) in renovation of wall at the end of n years, which will extend the life of the wall by y years; and n, i, and P are as defined in formula 1).

Inspections performed 15 years after a 1984–1985 in situ treatment with the same amine epoxy coating used in this CPC demonstration indicate that “the lifetime of the sheet piling will last for another 15 years and thus may be estimated to be at least 30 years” (see Appendix G). The project design engineer should request independent inspection reports of completed projects and verify claims. With competent persons (defined contractually) executing a project, the design engineer should expect that renovation will extend the service life of a treated steel sheet pile wall by at least 30 years.

### 4.3.3 Annual life-cycle cost savings

The annual life-cycle cost savings as a function of renovation cost, original service life, and additional years of service life are compared in Table 7.

The life-cycle cost comparisons in Table 7 use \$5,500 per linear foot for initial installation cost (P).

**Table 7. Life cycle cost comparisons to evaluate when renovation costs can justify service life extension.**

Table A. Renovation Cost per linear foot  
(L) = 20% of Initial Installation Cost, (P)

Additional Years of Service Life (Y)	Annual Life Cycle Cost Savings (%)					
	Original Service Life, (n) Years					
	25	30	35	40	45	50
+50	23%	18%	14%	11%	8%	6%
+40	22%	17%	13%	10%	8%	6%
+30	20%	15%	11%	9%	7%	5%
+20	16%	15%	11%	9%	7%	5%
+10	9%	6%	5%	3%	2%	2%

Table B. - Renovation Cost per linear foot  
(L) = 30% of Initial Installation Cost, (P)

Additional Years of Service Life (Y)	Annual Life Cycle Cost Savings (%)					
	Original Service Life, (n) Years					
	25	30	35	40	45	50
+50	21%	16%	12%	9%	7%	6%
+40	20%	15%	11%	9%	7%	5%
+30	18%	13%	10%	8%	6%	4%
+20	14%	13%	10%	8%	6%	4%
+10	6%	4%	3%	2%	1%	1%

Table C. Renovation Cost per linear foot  
(L) = 40% of Initial Installation Cost, (P)

Additional Years of Service Life (Y)	Annual Life Cycle Cost Savings (%)					
	Original Service Life, (n) Years					
	25	30	35	40	45	50
+50	19%	14%	11%	8%	6%	5%
+40	18%	13%	10%	7%	6%	4%
+30	15%	11%	8%	6%	5%	4%
+20	11%	11%	8%	6%	5%	4%
+10	4%	2%	1%	1%	0%	0%

Table D. Renovation Cost per linear foot  
(L) = 50% of Initial Installation Cost, (P)

Additional Years of Service Life (Y)	Annual Life Cycle Cost Savings (%)					
	Original Service Life, (n) Years					
	25	30	35	40	45	50
+50	17%	13%	7%	7%	5%	4%
+40	16%	11%	6%	6%	5%	4%
+30	13%	9%	5%	5%	4%	3%
+20	9%	9%	5%	5%	4%	3%
+10	1%	0%	-1%	-1%	-1%	-1%

When structures are treated in situ before the onset of heavy corrosion, the renovation investment is much lower. Conclusions from Table 7A are that design engineers can easily achieve an additional 30 years of service life and a 10%–20% reduction in life-cycle costs. One issue in implementing early sheet pile inspection and renovation projects is that port owners, users, and stakeholders may be reluctant to interrupt mission activities and associated economic activity. However, a qualified engineering and economics analysis can demonstrate the benefits of proactive sheet pile

maintenance and coating, particularly where significant portions of the seawall are approaching failure.

Based on Table 7D, it can be determined that approximately 50% of the original installation cost can be spent for 10 more years of life if the original service life of the structure was less than 30 years.

## 5 Conclusions and Recommendations

### 5.1 Conclusions

This dem/val project successfully demonstrated that the use of a limpet cofferdam, deployed and operated by qualified onsite personnel, can create a dry and safe subsurface workspace where crews can effectively rehabilitate and coat badly corroded steel sheet piles to a high standard of quality. Limpet deployment and dewatering was completed in 30 minutes or less in all locations but one, where a 24 in. (60 cm) gap between two piles had opened during the original construction. Once the limpet had been dewatered, leaks from the sheet pile into the limpet were sealed in 5–30 minutes depending on the leak size, location, and amount of flowing water.

The use of a high-performance amine epoxy coating, specially developed for this type of underwater corrosion protection, was readily sprayable at low temperatures and it fully cured under water as expected. The demonstrated high-build coating has a documented service life of 25–30 years both above and below the waterline.

Repairs of leaks and large perforations of the sheet pile structure cost 2–3 times more than the cost of final surface preparation, inspection, and coating work. A critical repair-related cost on this type of project is the labor-intensive removal of a thick layer of corrosion products so sheet pile condition can be directly assessed. These costs were relevant to this project since the selected section of wall was highly deteriorated after many years in service with no significant maintenance or repair.

An inherent limitation on any project of this type is that actual sheet pile wall conditions below the water line are difficult to ascertain before work begins. Early inspection by divers may provide valuable information, but it is also costly and produces a relatively small sample of data for extrapolation to a larger assessment. The true structural condition of the steel on this project was not known until all corrosion products were removed over a large area in the dry conditions of the limpet, and this is a limitation inherent in any method of subsurface structural rehabilitation.

The project inspector was able to perform all standard corrosion measurements of subsurface materials with no difficulty. Additionally, the inspector was able to collect and preserve biological samples and perform laboratory analysis in order to determine the root cause of the corrosion mechanism.

Corrosion patterns and bacteriological field tests showed the presence of three micro-organisms associated with the underwater corrosion damage, as listed below:

- Sulfur-reducing bacteria, which are anaerobic microbes that produce highly corrosive substances
- Sulfur-oxidizing bacteria, which can use sulfur compounds produced by SRB if oxygen or other electron acceptors like  $\text{Fe}^{3+}$  or  $\text{NO}_3^-$  are available to sulfuric acid
- Metal-reducing bacteria, which form films that may produce concentration corrosion cells on steel surfaces

These types of bacteria are known to promote corrosion of iron through reactions leading to the dissolution of corrosion-resistant oxide passivation layers on the metal surface. Pits grow at a much higher rate than the general corrosion rate. MIC rates can exceed 20 mil (0.5 mm) per year, creating conditions that can lead to accelerated structural failure.

## 5.2 Recommendations

### 5.2.1 Applicability

The limpet cofferdam and corrosion-resistant, rapid-cure epoxy coating should be considered by project managers to support a durable and time-efficient rehabilitation of a deteriorated steel pile structure. The combination of limpet technology and single-coat high-build amine epoxy coating may also be applicable for optimizing inspection and sustainment of steel surfaces below water while minimizing disturbances to harbor activities and the environment.

Before planning and committing to the use of a limpet in a sheet pile rehabilitation project, the stakeholders should conduct a thorough site assessment and prepare a preliminary cost basis for repairs.

**Initial Site Assessment.** An initial onsite visit is highly advisable for a feasibility analysis, site conditions, cost estimates, and verification of design details. Site assessment is a general inspection that may impact design or deployment of a limpet. The design engineer may obtain site data directly from the project owner and project documents, and then verify the information with an onsite investigation. When available, the design engineer should review prior inspection documents.

When prior inspection documents are not available, the design engineer should consider include a Level I (cursory) inspection over the entire sheet pile wall and a Level II (standard) inspection over a statistically significant representation of sheet pile wall that has been equally exposed to similar conditions.

The design engineer should record obvious major damage or deterioration due to overstress (collisions, ice), severe corrosion, or extensive biological growth attack. A thorough assessment should include the information listed below:

- Describe and measure the extent of marine fouling and corrosion.
- Confirm water levels, depths, and currents.
- Sound the mud bottom to locate any submerged obstructions.
- Confirm type and length of the sheet pile.
- Confirm geometric measurements of whales, caps, fendering systems, and other appurtenances.
- Evaluate site accessibility from both the shore and the water.
- Locate and identify any potentially hazardous materials.
- Locate and identify potential obstructions.

Site assessment data provides essential information to evaluate the following critical factors:

- Feasibility of deploying a limpet
- Limpet design and cost
- Initial estimate of equipment, labor, and material requirements to renovate the sheet pile wall

**Preliminary Cost Baseline Estimate.** Actual sheet pile wall conditions are difficult to ascertain before work begins. Contracting officers should define a baseline for repair specifications against which contractors

can bid. See Chapter 4, section 4.3, for a discussion of developing a baseline for estimating project costs.

### **5.2.2 Implementation**

This report provides supporting rationale for recommending in situ coating as a method for inclusion in the Unified Facilities Criteria (UFC) for Maintenance of Waterfront Facilities (UFC 4-150-07). This UFC describes various methods to repair and maintain underwater steel structures that suffer ALWC. Appendix H proposes language for revisions UFC 4-150-07 for the purpose of incorporating the demonstrated technologies.

Limpet dams are not mass-produced, but are basically one-of-a-kind structures. Being highly specialized equipment, they must be designed and assembled with careful attention to worker safety and environmental protection. Therefore, a limpet is not an item that most construction contractors could readily design and fabricate after a contract award. A poorly designed and constructed structure may not seal properly, posing unacceptable safety and environmental risks that could lead to work delays and very low productivity. If the use of a limpet dam is shown to be the most economical means for completing underwater sheet pile rehabilitation, then selecting a qualified contractor with proper equipment and documented experience is recommended.

Federal Acquisition Regulation (FAR) Part 15, “Contracting by Negotiation,” Subpart 15.3, “Source Selection,” prescribes policies and procedures for selection of a source or sources in competitive negotiated acquisitions. These rules are implemented by DoD in the corresponding Defense Federal Acquisition Regulation Supplement (DFARS) Part 215, Subpart 215.3 on source selection. The objective of source selection is to select the proposal that represents the best value for the government. Contracting by negotiation allows flexibilities in awarding a contract to satisfy an unusual or highly demanding scope of work. The contracting officer may engage in discussions with offerors and, in evaluating proposals, may also consider non-cost factors such as managerial experience, technical approach, historical data, and past performance. Appendix I presents a proposed synopsis for Requests for Proposals and Solicitations that require the use of a limpet. It includes special clauses that contracting officers may consider for solicitation documents. The synopsis includes provisions whereby offerors of limpet technology can protect applicable proprietary and patented intellectual property.

## References

29 CFR Chapter XVII, Part 1926. "Safety and Health Regulations for Construction." Washington DC: Occupational Safety and Health Administration, Department of Labor.

ASTM A242/A242M. "High-Strength Low-Alloy Structural Steel." West Conshohocken, PA: ASTM International.

ASTM D610. "Standard Test Method for Evaluating Degree of Rusting on Painted Steel." West Conshohocken, PA: ASTM International.

ASTM D714. "Standard Test Method for Evaluating Degree of Blistering of Paints." West Conshohocken, PA: ASTM International.

ASTM E1645. "Standard Practice for Preparation of Dried Paint Samples by Hotplate or Microwave Digestion for Subsequent Lead Analysis." (Superseded D1645 as of 2016.) West Conshohocken, PA: ASTM International.

CEBELCOR (Centre Belge d'Étude de la Corrosion [Belgian Center for Corrosion Study]). 1987 "Corrosion de Rideaux de Palplanches-Canal Gand-Terneuzen: Identification of Bacteriologically Induced Corrosion." Report NR2302. Waterloo, Belgium: CEBELCOR.

Christie, Jamison B. 2000. "Steel Pile Corrosion Survey Model: Inspection Procedures for Accelerated Corrosion on Marine Steel Piles." In *Port Technology International*, 11th ed., 43-50.

Defense Federal Acquisition Regulation Supplement (DFARS), Part 215, "Contracting by Negotiation," Subpart 215.3, "Source Selection." Washington, DC: Department of Defense.

Federal Acquisition Regulation (FAR), Part 15 "Contracting by Negotiation," Subpart 15.3 "Source Selection." Washington, DC: U.S. Government.

Fettig, Kenneth T., and Russel L. Jones. 1967. "Cost Effectiveness in Sheet-Steel Bulkhead Replacement, Maintenance, and Repair." Final Report covering period of August 31, 1966–December 31, 1966 for the Eastern Division of the Naval Facilities Command. Project No. Y-F015-15-07-004. Boston, MA: Peat, Marwick, Livingston and Co.

Gehrke, Tilman, and Wolfgang Sand. 2003. "Interactions Between Microorganisms and Physicochemical Factors Cause MIC of Steel Piling in Harbors." Paper #03557 in CORROSION 2003, National Association of Corrosion Engineers (NACE) conference held in San Diego, 16–20 March.

Herzberg, Eric F., Norman T. O'Meara, and Rebecca F. Stroh. February 2014. *The Annual Cost of Corrosion for the Facilities and Infrastructure of the Department of Defense*. Report DAC21T4. Tysons, VA: LMI Government Consulting.

ISO 8502-3. "Preparation of Steel Substrates before Application of Paints and Related Products -- Tests for the Assessment of Surface Cleanliness -- Part 3: Assessment of Dust on Steel Surfaces Prepared for Painting (Pressure-Sensitive Tape Method)." Geneva, Switzerland: International Organization for Standards.

ISO 8502-6. "Preparation of Steel Substrates before Application of Paints and Related Products -- Tests for the Assessment of Surface Cleanliness -- Part 6: Extraction of Soluble Contaminants for Analysis -- The Bresle Method." Geneva, Switzerland: International Organization for Standards.

ISO 8502-9. "Preparation of Steel Substrates before Application of Paints and related Products -- Tests for the Assessment of Surface Cleanliness -- Part 9: Field Method for the Conductometric Determination of Water-Soluble Salts." Geneva, Switzerland: International Organization for Standards.

Kumar, A., and L.D. Stephenson. 2002. "Accelerated Low Water Corrosion of Steel Pilings in Seawater." Proceedings of 30th PIANC-AIPCN Congress, held in Sydney, Australia.

\_\_\_\_\_. 2005. "Accelerated Low Water Corrosion on Steel Structures in Marine Environments." In *Port Technology*, 27th ed., 72–75.

\_\_\_\_\_. 2006. "Thirty-Three Year Study of Steel Pilings in Seawater." Paper 06303. Proceedings of CORROSION 2005, National Association of Corrosion Engineers (NACE), held in Houston, TX.

OMB (Office of Management and Budget). 1992. *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. OMB Circular No. A-94. Washington, DC: Office of Management and Budget.

PIANC Working Group 44. October 2005. "Accelerated Low-Water Corrosion." Final Report of Working Group 44 of the Maritime Navigation Commission. Brussels, Belgium: Permanent International Association of Navigation Congress (PIANC).

Sonck, Willy, and Eric Van Draege. 1994. Device for Sealing a Caisson in a Watertight Way. U.S. Patent 5,292,206, filed 16 September 1992, and issued 8 March 1994.

SSPC-SP 3. "Power Tool Cleaning." Surface Preparation Specification No. 3. Pittsburg, PA: The Society for Protective Coatings.

SSPC-SP 10/NACE No. 2. "Near-White Blast Cleaning." Joint Surface Preparation Standard. Pittsburg, PA: The Society for Protective Coatings.

UFC 4-150-07. "Maintenance and Operation: Maintenance of Waterfront Facilities," with Change 1. Washington, DC: Department of Defense.

USACE. 2014. *Safety and Health Requirements Manual*. EM 385-1-1. Washington, DC: Headquarters, U.S. Army Corps of Engineers.

Van Damme, L., and W. Vrelust. 1999. "Low Water Corrosion of Steel Pilings." *PIANC Bulletin* 101: 47–51.

Voight, Edward. February 2001. "New Technique Reduces Need for Underwater Work." *Engineer Update*. U.S. Army Corps of Engineers, Philadelphia District.

## **Appendix A: Technical Data Sheets for Humidur Coating Products**



# Technical Data Sheet

## HUMIDUR® ML Solvent Free Epoxy Coating

### Description

**Humidur® ML** is a two-pack, solvent free polyamine cured epoxy system with outstanding rust resisting capacities. Binding agents contain modifying components, thus ensuring excellent adhesion of the coating to the substrate. Pigmentation consists of specially developed abrasion resistant extenders and coloring pigments. High molecular weight elastifiers are added to provide for sufficient flexibility. The resulting composition combines excellent adhesion, abrasion and impact resistance, and is at the same time hydrophobic. Thus enabling the product to cure at low temperatures, even while immersed. It can be exposed to water immediately after application.

### Composition

**Humidur® ML** is a two-component system. Both the A and B component are delivered predosed in separate packaging. The base or A component contains non-crystallisable epoxy resins, high-tech modifying agents, elastifiers, lamellar abrasion and impact resistant fillers, and coloring pigments. The B component contains the polyamine hardener complex.

### Application

**Humidur® ML** is an efficient and proven solvent free anti-corrosion coating designed to protect steel as well as concrete structures from corrosion. **Humidur® ML** can be applied in one single layer up to thicknesses of 40 mils, depending on ambient temperature, using high-pressure airless spraying equipment. Overcoating if necessary can be done immediately on top of the previous clean **Humidur®** coat and does not need to be preceded by whip blasting. Adhesion onto the substrate as well as interadhesion between layers is excellent, even when cured at low temperature and high humidity. **Humidur® ML** is highly resistant to mechanical wear and immersion in mild chemicals and polluted waters. Since **Humidur® ML** can be 100% decontaminated, it is also suited for use in nuclear power plants.

**Humidur® ML** is also used for the protection against bottom plate corrosion in storage tanks for gasoline, kerosine, ...

### Specific Data

▪ Density @ 73°F		
base.....	approx. 12,2 lb/gal.	
hardener.....	approx. 9,5 lb/gal.	
mixture.....	approx. 11,7 lb/gal.	
▪ Solid content.....	100%	
▪ Recommended minimum dry film thickness	24 mils	
▪ Flash Point		
base.....	over 212°F	
hardener.....	over 212°F	
mixture.....	over 212°F	
▪ Pot life		
@ 73 °F.....	45 mins	
@ 86 °F.....	35 mins	
▪ Covering capacity		
theoretical @ 24 mils	68 sq ft/gallon	
theoretical @ 40 mils	40 sq ft/gallon	
▪ Viscosity @ 73°F		
@ CSS 0,10 PSI	7,25.10 <sup>-4</sup> ±	1,45.10 <sup>-4</sup>
mixture.....	PSI.s	
▪ Mixing ratio A:B		
by weight.....	5,0 : 1	
by volume.....	3,9 : 1	
▪ Min. overcoating time	wet-in-wet	
▪ Colors.....	25 different shades	
▪ Shelf life.....	12 months in unopened pails stored at max. 77°F in a dry place.	
▪ Thinning.....	Adding thinner and/or diluents is under any circumstances strictly forbidden.	

### Important

**This coating system should not be thinned**

The present edition of this technical data sheet replaces all previous ones. Specific data have been drawn up as accurately as possible and are based on our knowledge regarding the above mentioned product until 10/08/2009.  
For more information, please contact: Acotec NV, Industrielaan 6, B-9111, Ghlin (Belgium). Tel. +32 475 20 80 88.



# Technical Data Sheet

## HUMIDUR® BAML Solvent Free Epoxy Coating

### Description

**Humidur® BAML** is a low-viscosity variant of the Humidur® ML system, intended for easier brush application. **Humidur® BAML** is a two-pack, solvent free polyamine cured epoxy system with outstanding rust resisting capacities. Binding agents contain modifying components, thus ensuring excellent adhesion of the coating to the substrate. Pigmentation consists of specially developed abrasion resistant extenders and colouring pigments. High molecular weight elastifiers are added to provide for sufficient flexibility. The resulting composition combines excellent adhesion, abrasion and impact resistance, and is at the same time hydrophobic. Thus enabling the product to cure at low temperatures, even while immersed. It can be exposed to water immediately after application.

### Composition

**Humidur® BAML** is a two-component system. Both the A and B component are delivered predosed in separate packaging. The base or A component contains non-crystallizable epoxy resins, high-tech modifying agents, elastifiers, lamellar abrasion and impact resistant fillers, and colouring pigments. The B component contains the polyamine hardener complex.

### Application

**Humidur® BAML** is an efficient and proven solvent free anti-corrosion coating designed to protect steel as well as concrete structures from corrosion. **Humidur® BAML** can be applied in one single layer up to thicknesses of 8 mils, depending on substrate temperature, using high-pressure airless spraying equipment, a paint brush or a roller. Overcoating if necessary can be done immediately on top of the previous clean **Humidur® BAML** coat and does not need to be preceded by whipblasting. Adhesion onto the substrate as well as interadhesion between layers is excellent, even when cured at low temperature and high humidity. **Humidur® BAML** is highly resistant to mechanical wear and immersion in mild chemicals and polluted waters. The temperature of the surface and of the coating should be at least 68° F in order to obtain a properly coated surface.

### Important

**This coating system should not be thinned**

### Specific Data

▪ Density @ 73° F base.....	± 11,1 lb/gallon
hardener.....	± 9,5 lb/gallon
mixture.....	± 10,8 lb/gallon
▪ Solid content.....	100%
▪ Dry Film Thickness should be considered per application area. max. in 1 layer @ 73° F	8 mils
▪ Flash Point base.....	over 212°F
hardener.....	over 212°F
mixture.....	over 212°F
▪ Pot life @ 73° F.....	45 mins
@ 86° F.....	30 mins
▪ Covering capacity theoretical @ 12 mils	± 135 sq ft/gallon
theoretical @ 14 mils	± 116 sq ft/gallon
▪ Viscosity @ 73° F @ CSS750Pa	3,5 ± Pas
mixture.....	
▪ Mixing ratio A:B by weight.....	4,19 : 1
by volume.....	3,59 : 1
▪ Min. overcoating time	wet-in-wet
▪ Colours.....	5 different shades : grey, olive green, white, black, blue
▪ Shelf life.....	12 months in unopened pails stored at max. 77° F in a dry place.
▪ Thinning.....	Adding thinner and/or diluents is under any circumstances <b>strictly forbidden</b> .

The present edition of this technical data sheet replaces all previous ones. Specific data have been drawn up as accurately as possible and are based on our knowledge regarding the above mentioned production as of 2000.  
For more information, please contact: Indurac 217, Zuid 117, 9220 Herentals (Belgium),  
Phone +32 35 320000.



# Technical Data Sheet

## HUMIDUR® PML Solvent Free Epoxy Coating

### Description

**Humidur®PML**, based on a two-component epoxy, is solvent free, free of coal tar and has a high resistance against crystallization. **Humidur®PML** contains modifying components which assure a good adhesion on steel as well as on concrete. The hardening of **Humidur®PML** can happen in the free atmosphere as well as under water. **Humidur®PML** has a though flexible film with an excellent mechanical resistance and anti-corrosive qualities.

### Composition

A set of **Humidur®PML** consists of two components :

- Component A : epoxy resin + abrasion resistant extenders + colour pigments.
- Component B : polyamine hardeners + abrasion resistant extenders. The components are predosed.

### Application

Extremely suitable product for the filling of unevennesses and pits in concrete surfaces as well as in corroded steel surfaces. It serves as an equalization of the surface, preceding the application of the protective Humidur® coating on these surfaces. The specific advantage is that Humidur® coating can be applied immediately wet in wet on the **Humidur®PML**, so that both systems can net.

### Preparation of the surface to be treated

If concrete : The concrete surface should be pure, homogenous and deburred. It should be free of dust, fungi, cement parts and soft or brittle parts. The best result is obtained by dry sandblasting.

If steel : The surface is sandblasted to a degree of Sa 2,5 of the ISO 8501-1 standard by means of sandblasting material such as sand, slag, corund, steel grains or cast iron grains. The sandblasting material should have sharp angles and be free of clay, oil, humidity, soluble salts or any other foreign object.

### Use

After both components have been mixed, **Humidur®PML** is applied with a spatula, a putty knife, silicone tube or a plasterer's trowel on a conformly prepared surface, so that an equal surface is obtained. On steel surfaces, this is best done within 2 hours after sandblasting at a surrounding temperature that is 1° higher than the dew point. After equalizing with **Humidur®PML**, Humidur® ML can be used as top layer wet-in-wet or after curing of the **Humidur®PML** layer.

The present edition of this technical data sheet replaces all previous ones. Specific data have been drawn up as accurately as possible and are based on our knowledge regarding the above mentioned products up to 07/2009.  
For more information, please contact : Acotec N.V. Industrieweg 5, Zuid HZ, 5130, Antwerp (Belgium).  
Tel: +32 3 23 36 00 Fax: +32 3 23 36 00 88

### Cleaning of the equipment

Humiflush

### Specific Data

▪ Density	
base.....	± 1,54 kg/l (can vary with the colour)
hardener.....	± 1,12 kg/l
mixture.....	± 1,45 kg/l
▪ Consumption.....	depends on the surface that has to be equalized e.g. sandblasted concrete surface : ± 800 g/m <sup>2</sup>
▪ Shelf life	12 months in unopened pails stored at max. 25°C in a dry place.

## HUMIFLUSH

### Technical data sheet

**DESCRIPTION :** Humiflush is a mixture of specific solvents, for the effective cleansing of 2-component epoxy systems.  
This solvent composition was developed in function of the solubility of the raw materials used in the Humidur® epoxy systems.  
Humiflush has, as opposed to methylethylketone, a higher flash point.  
Humiflush is also less aggressive towards the pump sealings.

**COMPOSITION :** Humiflush is a mixture of xylene, butanol and 2-methoxy-1-methylethylacetate.

**APPLICATION :** Cleaning of equipment and application material during or immediately after the application of the Humidur® epoxy system.  
  
Humiflush can be used for the cleaning of the Airless pump, the pistol, the spraying hose as well as for the cleaning of brushes or rolls or for accidental spilling of non-cured Humidur® product.

**CLEANING OF THE MATERIAL :** Immerge the brush, roll or pistol in a bucket filled with Humiflush. After a few minutes, by means of a cleaning brush or by hand (put on solvent resistant gloves), the soiled parts can be cleaned. Repeat this until a pure Humiflush product remains.  
  
By means of a dry rag or cloth, the solvent can be removed from the cleaned parts.



*Cleaning of the pump and hoses :*

First phase : pump up Humiflush cleansing agent into the pump and the spraying hoses.

As soon as you notice cleansing agent in the pistol, stop pumping and let off the pressure of the spraying pistol after which the spraying hose is disconnected from the spraying pistol.

The pistol is then cleaned by hand separately.

Second phase : Next, you can put the spraying hose in the Humiflush cleansing agent that will be pumped up and again start the pump under low pressure. After 5 to 10 minutes new, clean Humiflush is used for further cleaning. The pump and the hose are visibly clean as soon as no discolouring of the clean Humiflush mixture can be noticed any longer.

Third phase : If the pump will be out of action for several days, it is best to remove the cleansing agent from the pump and the hose and replace it by e.g. diesel fuel. This will ensure a longer lifetime of the pump's gaskets and of the spraying hose.

**PRECAUTIONS :** The usual prescriptions for safety and hygiene concerning work with epoxy resins. Special strict personal hygiene amongst others with regard to clothing, which should be renewed each day, no food, no drink, no smoking, cleaning, care of the skin after each working phase.

**INDIVIDUAL MEANS OF PROTECTION**

- protection of the bronchial tubes, face and eyes with a DIN-filtering device type A + face shield or else a non-autonomous apparatus with air supply, connected with a tube to a compressor of the NIOSH type C.
- protection of the hands : gloves with cuffs impermeable to ECH, made of PE, PP or PVC.
- protection of the skin : clothing impermeable to ECH, made of PE, PP or PVC (apron, shoes, boots, overalls). Cotton is also recommended. The use of a protective skin cream is extremely efficient.

To clean soiled skin parts, follow the instructions of the manufacturer : WARM WATER + NON-ALKALINE SOAP or special detergents, paper throwaway towels, nourishing and regenerating skin cream.



**TECHNICAL  
DATA :**

Physical form :	liquid
Viscosity at 20° C (mPas) :	0,788
Colour :	colourless
Flash point :	25,8° C
Density :	0,879 g/cm <sup>3</sup>

The present edition of this technical data sheet replaces all previous ones. Specific data have been drawn up on an experimental basis and are based on our knowledge regarding the above mentioned product. It is up to the user to verify the information given. For more information, please contact : Tonge NV, Prinsstraat 6, Zingem, Belgium. Tel: +32(0)3 63 70 00 Fax: +32(0)3 63 70 00 E-mail: tonge@tonge.be



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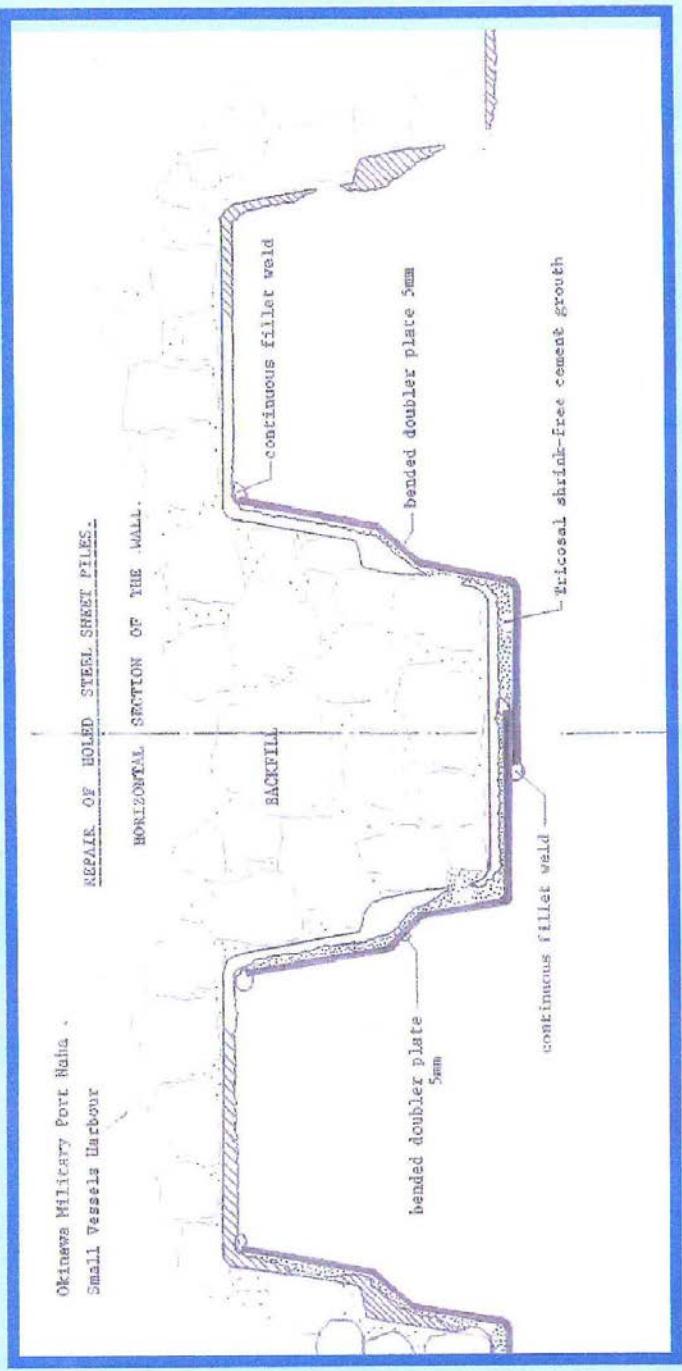
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## Appendix B: Diagram of Sheet Pile Wall Repair Above Waterline

### Repair of Above Water Corrosion

Blast area

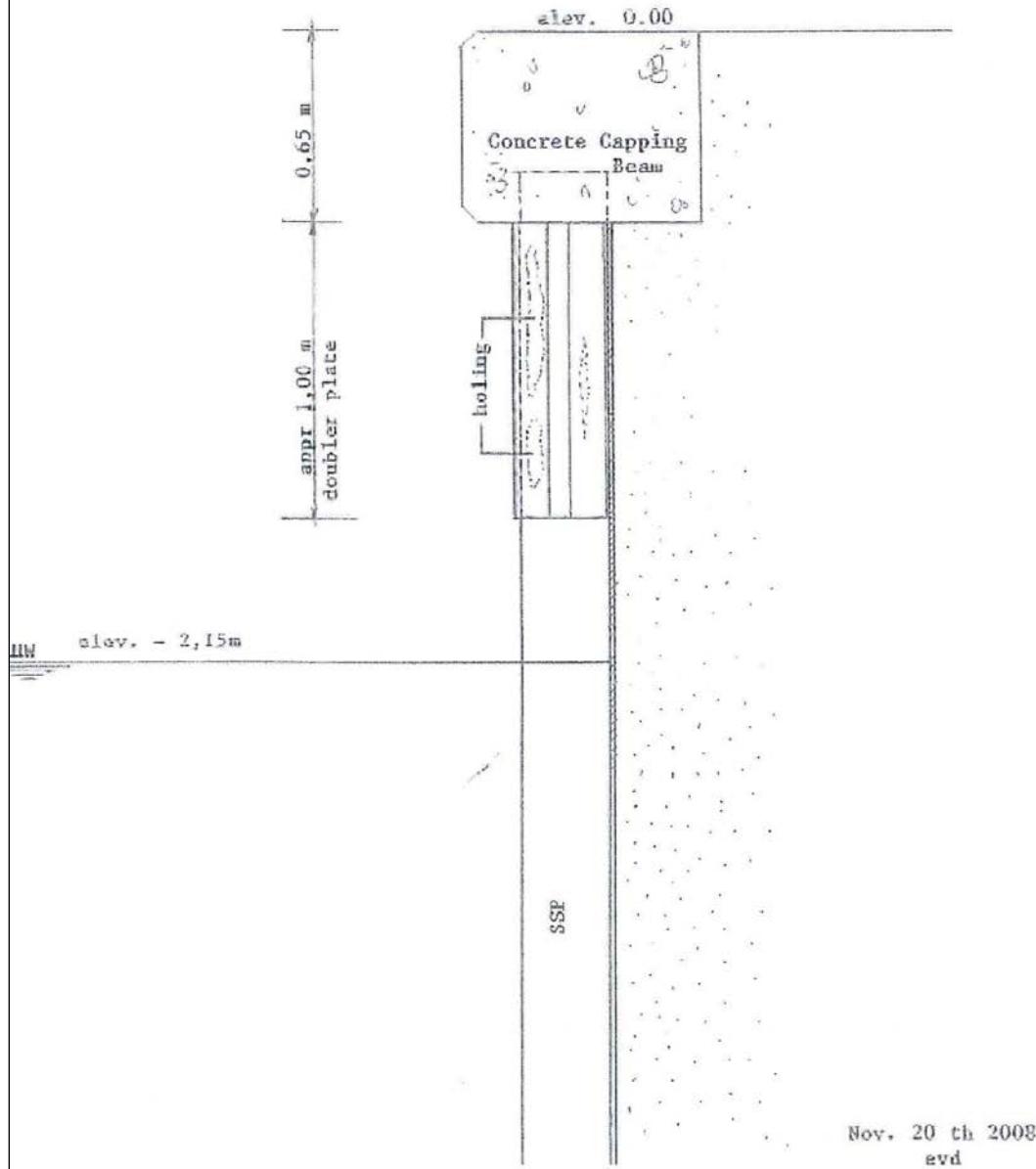
Plug holes with concrete grout  
Weld preformed 5mm steel panels in place  
Reblast



Okinawa Military Port Naha  
Small Vessels Harbour

REPAIR OF HOLED STEEL SHEET FILES

VERTICAL CROSS SECTION OF THE WALL.



## Appendix C: Bacteriological Test Methods to Identify Causes of Corrosion



Figure 1: Coupon of black substance taken from steel surface

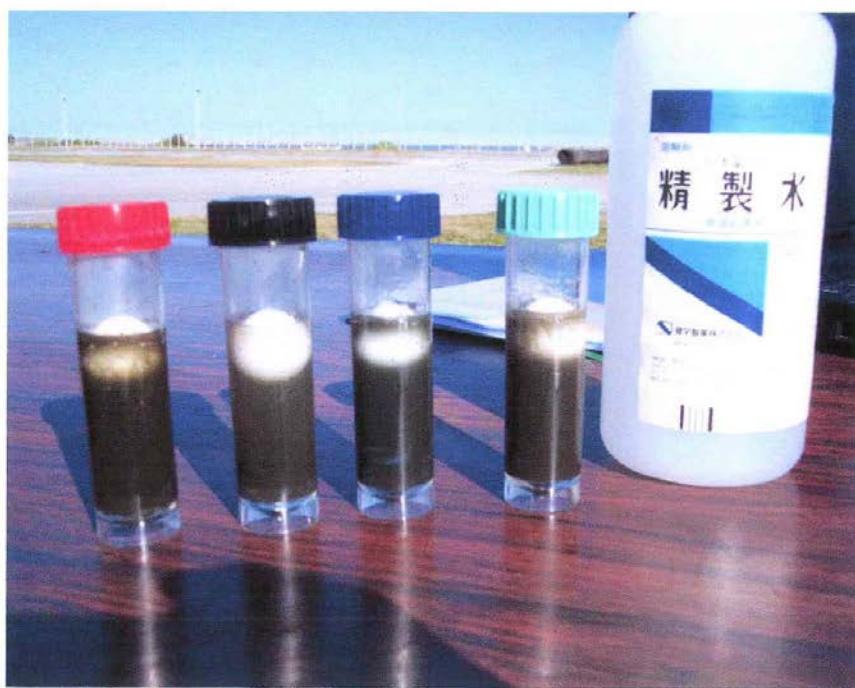


Figure 2: Black substance divided into different test tubes, each searching for a different kind of bacteria



**Figure 3: Results of the different test show that different kinds of microbacteriological elements are present (from left to right: sulphate reducing bacteria (black cap) - Biochemical oxygen demand (light blue cap) - Iron related bacteria (red cap) - Acid producing bacteria (purple cap).**

This test is called the BART-test and is the correct way to determine the presence of bacteriological bacteria. To determine the quantity of the found bacteria, a laboratorial research is required.

As concluded from this test, all the measured bacteria's were present on the wharf in the Port of Naha on the island of Okinawa in Japan.

Please find more information about the BART-test in annex.

## 1.0 ABOUT THE BART™

The environment contains a myriad of different bacteria that are all capable of causing problems. These problems can range from slimes, plugging, discoloration and cloudiness to corrosion and infections. Such a wide variety of bacteria are not easy to detect and identify using a single test and yet their impact can make the water unsafe, unacceptable or unavailable due to losses in flow through plugging or equipment failure due to corrosion. The biological activity reaction test (BART™) is a water testing system for nuisance bacteria and can involve several different tests. These tests detect the activity (aggressivity) of these nuisance bacteria by the time lag (TL, measured in the number of days from the start of the test to when a reaction is observed). The longer the TL before the observation of activity, the less aggressive the bacteria are in that particular sample.

There are seven different tests that are recognizable by colored cap coding and the initial letters preceding the word BART™. These include selective tests for:

Iron Related Bacteria	IRB-BART™	Red Cap
Sulfate Reducing Bacteria	SRB-BART™	Black Cap
Heterotrophic Aerobic Bacteria	HAB-BART™	Blue Cap
Slime Forming Bacteria	SLYM-BART™	Green Cap
Denitrifying Bacteria	DN-BART™	Grey Cap
Nitrifying Bacteria	N-BART™	White Cap
Fluorescing Pseudomonads	FLOR-BART™	Yellow Cap
Acid Producing Bacteria	APB-BART™	Purple Cap
Biochemical Oxygen Demand	BOD-BART™	Light Blue Cap

Each of these bacterial groups cause different problems and often a combination of these tests should be used to determine which bacteria are present and causing problems. In the event that further information beyond presence/absence is needed, information on these reactions can be accessed using the Internet: [To read all of the reactions, lift the inner test vial carefully out of the outer BART™ test vial and view through the inner vial against an indirect light.](#)

### 1.1 METHODOLOGIES

A common list of the methodologies and applications would be:

IRB-BART™ test becomes positive when there foam is produced and/or a brown color develops as a ring or dirty solution. The TL (time lag) to that event is the delay. A negative has no brown color developing, no foaming or clouding. This test is commonly used to detect plugging, corrosion, cloudiness and color. The bacteria that may be detected by this test include iron oxidizing and reducing bacteria, the sheathed iron bacteria, Gallionella, pseudomonad and enteric bacteria.

SRB-BART™ A very simple test to perform in which a positive test occurs when there is a blackening either in the base cone of the inner test vial (80% of the time) or around the ball (20% of the time). The culture medium is specific for the sulfate reducing bacteria, such as Desulfovibrio and Desulfotomaculum. This is a more specific test and specifically relates to corrosion problems, taste & odor problems ("rotten egg" odors), and blackened waters. Slimes rich in SRB tend to also be black in color. A negative indication occurs when there is an absence of blackening in the base cone of the inner test vial or around the ball.

HAB-BART™ There is a very real need to determine the amount of heterotrophic aerobic bacterial activities in some wastewater, particularly those that are aerobic. Here, biodegradation may be a primary concern, such as on a hazardous waste site. This test relies upon the ability of the heterotrophic aerobic bacteria to reduce a methylene blue dye. To add the methylene blue to the sample, the test vial once charged is simply placed upside down for 30 seconds or 5 minutes in a saline environment, to allow the blue color to develop. A positive is detected by the blue color becoming bleached (due to the activity of methylene blue reductase). Bleaching may begin at the base of the test vial or just below the ball. Note that a residual blue ring is likely to remain around the ball, but this does not mean heterotrophs are absent. A negative indication occurs when there is an absence of the blue color becoming bleached. This test is used to detect slimes, plugging, taste & odor, cloudiness and can also detect the amount of aerobic heterotrophic activity on hazardous waste sites.

SLYM-BART™, some bacteria can produce copious amounts of slime that can contribute to plugging, loss in efficiency of heat exchangers, clouding, taste and odor problems. This is one of the most sensitive BART™ tests. A positive involves a cloudy reaction in the inner test vial often with thick gel-like rings around the ball. A negative test remains clear.

FLOR-BART™ A major group of aerobic heterotrophs are the pseudomonads. These bacteria are very well adapted to breaking down some chemicals such as jet fuel and solvents but also can infest recreational waters and cause conditions ranging from skin, eye, ear, and nose infections to pneumonia-like infections. The infectious pseudomonads do produce an ultra-violet fluorescence that is usually a pale blue color. Presence for this test means that either a greenish-yellow or a pale blue glow is generated by the careful application of an ultraviolet light just below the ball. The degraders tend to generate the greenish-yellow glow while the health risk group generates the pale blue glow. A negative indication occurs when the sample remains clear.

DN-BART™ Nitrates in water are a serious health concern particularly for babies. There is one group of bacteria called the denitrifying bacteria and many of these are able to reduce the nitrate to nitrogen gas. In this test, this gas forms a foam of bubbles around the ball, usually within three days. The presence of this foam by the end of day two is taken to be an indication of an aggressive population of denitrifying bacteria. Absence of foam, regardless of any clouding of the water, indicates that the test is negative for the detection of denitrifying bacteria. This test is applicable to any waters where there is likely to be potential septic or organic contamination. The presence of denitrifiers would indicate a potential health risk due to either septic wastes or nitrates in the water.

## 1.2 The six W's of the BART™ Testers

There are numerous ways in which microbes can become a nuisance in water. Often these events are ignored, considered inevitable or put down to simple physical and chemical effects. Ignorance may be bliss, but it is expensive. These microbes can cause corrosion, plugging, failing water quality and the shortening in the life span of the installation. In today's world, disposability is being replaced with sustainability and ignorance replaced with knowledge. There has been a considerable lack of attention paid to the nuisance events caused by bacteria other than those associated with hygiene risks. In ground waters, it has been a common practice until a decade ago to consider the environment to be essentially sterile and so microbial events were not considered important. In surface waters, larger and more obvious organisms tended to receive more attention than the slimes and clouds in the water. Today, it is becoming recognized that microbes are present in all waters and that they have a nuisance impact that needs to be managed if sustainability is to be achieved. This document addresses the advantages of becoming more aware of the microbes and their activity in water. It should be remembered that there is no such place as a totally sterile water environment and that, if the microbes are active, there will be affects on the environment.

### 1.2.1 WHAT ARE THE BART™ TESTERS?

BART™ stands for the patented biological activity reaction test. As the name implies, the test detects biological activity by looking for activities and reactions. Activities relate to growth events such as the formation of clouds, slimes, and gels. Reactions relate to the manners in which the microbes interact within the BART™ test. These reactions may take the form of color changes, generation of gasses, and precipitation. The unique nature of the BART™ test which makes it very different, and possibly superior, to the agar techniques is the fact that the water used in the test all comes from the sample and contains the microbes still within their natural environment. The water in the agar methods comes with the agar but it is tightly bound. This means that the microbes have to be taken from the water, placed into contact with the agar surfaces, and expected to "mine" the bound water for growth from the agar. Many microbes in the environment are not able to easily do this and so may be missed using agar cultural techniques (i.e., no grow, no show, no count and so not important).

The BART™ uses a unique system for encouraging the microbes to grow in the test. First, there is normally no dilution of the sample. Secondly, the sample becomes adjusted to a variety of different habitats by the nature of the BART™. Thirdly, the microbes that can be active and/or react with the selective conditions created within the BART™ test can be considered to belong to a specific group of bacteria (e.g., iron related bacteria). These selective conditions are created using two devices. The first (1) is a floating ball, FID-floating intercedent device, that restricts the entry of oxygen into the sample below. The second device (2) is the use of a crystallized deposit of selective nutrients, which sits in the bottom of the tube and encourages the activities and reactions by a specific group of microbes. In the first device, the oxygen enters around the floating ball to allow oxygen requiring (aerobic) microbes to grow. They will use all of the oxygen diffusing down so that the sample further down becomes devoid of oxygen. This volume underneath becomes suitable for the growth of microbes that do not require oxygen (anaerobic). Thus, the single BART™ provides environments which are aerobic (oxidative) and anaerobic (reductive). Essentially this is a reduction-oxidation gradient with a transitional zone (redox front) in the middle.

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## Appendix D: Evaluation of Coating Condition After 6 Months

### General view of the bulkhead

Appearance of the bulkhead after 6 months



December 2008

June 2009





## Evaluation Degree of Rusting on the Painted Surface and Degree of Blistering of the coating

### **Summary**

The bulkhead was inspected on June 8th 2009 from a " basket " , hanging from a mobile hydraulic crane . The whole surface was , at extremely low tide , meticulously inspected for defects and the dry film thickness was measured ( see appendix O ).

The surface under water was visible till approx. minus 3 meter under the coping beam. No defects to be observed.

In the zone between the coping beam and 2,5 m down, only in the top 1,50 m area some pinholes and minor mechanical damage was detected .

#### Degree of Rusting .

The few small defects and pinholes with rust stains are according ASM D610-08 is far below the allowed threshold of 0,01% of the total surface . So the General rust grade and the Spot Rusting Grades are equal to 10 , meaning negligible .

#### Degree of Blistering .

The surface shows no signs of blistering . This brings us also in the numerical scale of 10 according to ASTM D714-02 .

Further in annex we show a number of representative pictures of the defects.

#### Comments :

The area in which the pinholes are found, corresponds with the area of severe pitting. During spraying air may be trapped and while expanding produced a bump and a small hole in the not yet cured coating . This effect is not exclusive for this project alone. Instead of spending too much effort in macro-filling each small crater , these small defects that may show up after some time, are repaired later which is more practical and economical .

During the inspection at 12 months , a couple of months away , all these defects will be corrected.

### **Result for total inspected surface**

Rust grade:	10	Less than 0,01% rust
General Rusting grade:	10-G	None
Spot Rusting grade:	10-S	Less than 0,01% rust
Pinpoint Rusting grade:	10-P	Less than 0,01% rust
Blistering grade:	10	None



Some Pictures of small defects and pinholes

Pile n° 20  
Holiday



Pile n° 27  
One pinhole



Pile n° 23  
Two pinholes



Pile n° 23  
After brushing

## Appendix E: Evaluation of Exposure Panels After 6 Months

### Tests preformed on the substrate

Site: Military port Naha  
Performed by: Kurt Claeys  
Date: November 21, 2008

**Coordinates:** Test plates

**Rust degree** (ISO 8501-1)  
(before blasting)

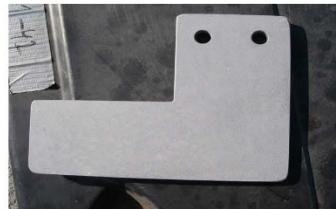
Rust grade: A

No corrosion



**Purity degree** (ISO 8501-1)  
min. Sa 2 1/2

Sa 3



#### Investigation of surface dust: transparent adhesive tape (amount of dust <4 of ISO 8502-3)

Description of the test site:	on extra test plate
Description of the adhesive tape:	light spots of dust visible, particles are small, just visible
Result quality degree:	2 < 4
Class:	3 < 4

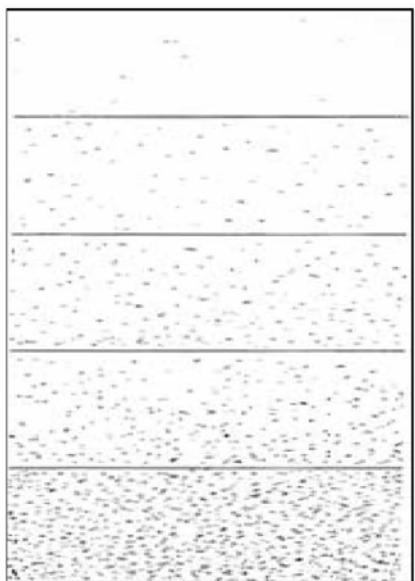


TABLE 1 - Dust Size Classes

Class	Description of dust particles
0	Particles not visible under X 10 magnification
1	Particles visible under X 10 magnification but not with normal or corrected vision (particles < 50 µm in diameter)
2	Particles just visible with normal or corrected vision (particles 50 µm to 100 µm in diameter)
3	Particles clearly visible with normal or corrected vision (particles up to 0,5 mm).
4	Particles between 0,5 mm to 2,5 mm
5	Particles larger than 2,5 mm

**In vestigation of condensation:**

Measurment equipement:	Temperature/humidity meter		Infrared thermometer	
	Fluke 971	95941487	Fluke 61	94640028
Serial N°:		°C	F	
Surface temperature:	21,6	70,9		
Temperature of air:	24,8	76,6		
Humidity of air:	41,80 %		<	80 %
Dewpoint:	11	51,8		
Wet Bulb temperature:	16,5	61,7		

**Determination of roughness:** to be compared with COMPARATOR (>segm; 1) Visual inspection of the roughness, if required by means of a comparator:

Measurment equipment: elcometer 125  
 Serial N°: 8047  
 segm. 1 segm. 2



Segm. 4

roughness between segment nr.: 2  
 and segment: 3

&gt; 1



Segm. 3

#### Investigation for chlorides & salts: Breasle patch test ISO 8502-6/ISO8502-9 conductivity analysis

Maximum value of chlorides allowed:	60	mg/m <sup>2</sup>	6486,49	µg/ft <sup>2</sup>	6,49	mg/ft <sup>2</sup>
Maximum value of salts allowed:	90	mg/m <sup>2</sup>	9729,73	µg/ft <sup>2</sup>	9,73	mg/ft <sup>2</sup>

test N°	Zero Value	Measurment	result	chlorides			Salts		
				µS	µS	µS	mg/m <sup>2</sup>	µg/ft <sup>2</sup>	mg/ft <sup>2</sup>
1	1,8		7,7	5,9	23,6	2551,4	2,6	35,4	3827,0
2									
3									
4									

#### Humidur conditions

Temperature "bain marie":	38,6 °C	101,5 F
Paint temperature:	32,2 °C	90,0 F
Sprayhose temperature:	26,5 °C	79,7 F
Sprympump lowpressure inlet:	6 bar	87 psi
Sprympump highpressure out:	408 bar	5916 psi
Quantity humidur P used:	0 kg	0,00 Lb
Quantity humidur BAML used:	0 kg	0,00 Lb
Quantity humidur ML used:	1 kg	2,68 Lb

Square area to coat:	0,768 m <sup>2</sup>	8,26668 ft
Consumed per square:	1,3 kg/m <sup>2</sup>	0,3241 Lb/ft <sup>2</sup>

**Measurment of wet layer thickness** by wet film thickness gauge.

Nominal:	600 µm	24 Mils
minimum:	400 µm	16 Mils

Measurment Nº	µm	Mils
1	750	29,53
2	800	31,50
3	600	23,62
4	600	23,62
5	650	25,59
6	700	27,56
7	700	27,56
8	750	29,53
9	800	31,50
10	600	23,62

average:	695	27,36
maximum:	800	31,50
minimum:	600	23,62

**Remarks:**



weight of one testplate not coated is:      2157,1 gr  
     76,089 ounce  
     4,756 lbs



Retrieval of Humidur® ML coated coupons after 6 months of exposure

- Evaluation of Degree of Corrosion
- Evaluation of Degree of Blistering
- Pictures

Evaluation of the coupons was preformed by Ing. Wilfried Hendrix on June 25<sup>th</sup>, 2009 at Acotec Belgium.

**Coupon IN 8 - 2.5 C before cleaning :**

small acorn barnacles are visible , dimensions till 1 cm  
One barnacle has a diameter of 2,5 cm  
small quantities of algae growth cover the complete surface  
rust color is visible at the backside in the fixing area



front side



back side



<b>Coupon Number</b>	<b>ASTM D 714</b> Evaluation Degree of Blistering		<b>ASTM D 610</b> Evaluation Degree of Rusting		
	Size	Frequency	Rust Grade	Spot	General Pinpoint
IN 8 - 2.5 C					
Front	10	none	10	none	
Back	10	none	10	none	

**Coupon IN 8 - 2.5 C after cleaning :**

**Coupon IN 16 - 1 C before cleaning :**

No marine growth on this coupon , only some dirt  
rust color is visible at the backside in the fixing area



<b>Coupon Number</b>	<b>ASTM D 714</b> Evaluation Degree of Blistering		<b>ASTM D 610</b> Evaluation Degree of Rusting		
	Size	Frequency	Rust Grade	Spot	General Pinpoint
Front	10	none	10	none	
Back	10	none	10	none	

Coupon IN 16 - 1 C after cleaning :



**Coupon IN 32 - 2.5 C before cleaning :**

small acorn barnacles are visible , dimensions till 1 cm  
small quantities of algae growth cover the complete surface  
rust color is visible at the backside in the fixing area



<b>Coupon Number</b>	<b>ASTM D 714</b> Evaluation Degree of Blistering		<b>ASTM D 610</b> Evaluation Degree of Rusting		
	Size	Frequency	Rust Grade	Spot	General Pinpoint
IN 32 - 2.5 C					
Front	10	none	10	none	
Back	10	none	10	none	

**Coupon IN 32 - 2.5 C after cleaning :**



Retrieval of uncoated coupons after 6 monthsCoupon IN 8 - 2.5 S

Coupon IN 16 - 1 S



Coupon IN 32 - 3.5 S

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## Appendix F: Evaluation of Coating Condition After 11 Months

### Evaluation Degree of Rusting on the Painted Surface and Degree of Blistering of the coating

#### **Summary**

The bulkhead was inspected on November 30<sup>th</sup> 2009 from a basket, connected to an articulating boom lift. The whole surface was, at extremely low tide, meticulously inspected for defects and some adhesion tests were taken on random chosen spots. Also we noticed that the quantities of barnacles and algae, at the surface, were notable increased. Barnacles and vegetation are easily removed and the coating, may be cleaned to original conditions.

The surface under water was scraped, brushed and cleaned from barnacles at approx. 10 outpans till minus 3 meter under the coping beam. Coating looks very good and no defects were found.

In the zone between the coping beam and 2,5 m down, there was no increasing in pinholes or small defects after 12 months in comparison with the inspection 6 months earlier.

#### Degree of Rusting .

The few small defects and pinholes with rust stains, already discovered 6 months earlier are according ASM D610 is far below the allowed threshold of 0,01% of the total surface .  
So the General rust grade and the Spot Rusting Grades are equal to 10 , meaning negligible.

#### Degree of Blistering .

The surface shows no signs of blistering . This brings us also in the numerical scale of 10 according to ASTM D714-02.

#### Comments :

The pinholes and minor defects that where found on the first inspection were repaired on December 1st & 2nd, 2009.

And this in following procedure: removal of the pinholes with grinder or by drilling  
clean the area with distilled water and tissue  
further cleaning with acton and dry the area with hot air.  
Touch up with Humidur® PML

Also the same procedure was used after the adhesion tests.

#### **Result for total inspected surface**

Rust grade:	10	Less than 0,01% rust
General Rusting grade:	10-G	None
Spot Rusting grade:	10-S	Less than 0,01% rust
Pinpoint Rusting grade:	10-P	Less than 0,01% rust
Blistering grade:	10	None



## Adhesion test

Pile n°	depth	position	Force Mpa	% glue	% adhesion	% cohesion
3	-0,7	web	11,7	100	0	0
5	-1,7	inpan	8	0	100	0
13	-0,8	outpan	16,2	95	0	5
24	-1,2	outpan	16,8	100	0	0
31	-0,5	web	9,5	100	0	0



articulating boom lift



basket of articulating boom lift

## Pictures of Adhesion test



position of dolly



the red pointer give the result of adhesion test



**Pictures of repair procedure**

grinding or drilling



cleaning with distilled water and tissue



Degreasing with aceton



applying the coating

Inspection and repairs were carried out from November 30<sup>th</sup> till December 21<sup>d</sup>, 2009  
by Eric Van Draege and Kurt Claeys.



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## Appendix G: In Situ Inspection of Past Humidur Application After 24 Years

### HUMIDUR ML AT ZELZATE AFTER 24 YEARS

One of the oldest applications of Humidur ML can be found on the Canal Ghent-Terneuzen. These applications were performed 1984 - 1985 . This location is investigated regularly, for the follow-up of the condition of the corrosion protection .

#### General condition :

After 25 year the Humidur coating is in good condition.

Corrosion is found only on some spots below the concrete coping beams, on the interlocks, on the spots with insufficient coating layer thickness and where mechanical damage occurred.





At the bottom edge it is clear , that the Humidur ML that was applied in the past, has stopped corrosion. This picture demonstrates that corrosion continues deeper than the narrow band of 1 meter that was called to be typical for ALWC. Remark also the striations, some corrosion specialists call it : the "finger print" of MIC.



edge of the original 1985  
Humidur - application  
at -1,20m under water



On Wednesday 24th of June 2009, adhesion tests were performed on this location

Adhesion tester used : PAT GM01  
glue used : Loctite 415

	<b>Location</b>	<b>Result</b>	
Dolly 1	above the water level 60 cm below the coppering beam	17,0 Mpa	100 % glue failure
Dolly 2	below the water level 10 cm below intermediate beam	10,2 Mpa	95 % glue failure 5 % cohesion failure
Dolly 3	below the water level 60 cm below intermediate beam	17,4 Mpa	75 % glue failure 25 % adhesion failure
Dolly 4	below the water level 20 cm below intermediate beam	17,4 Mpa	90 % glue failure 10 % adhesion failure



Humidur ML layer thickness : Phynix Pocket-Surfix

Average layer thickness : 829,5 µm  
Maximum layer thickness : 1478 µm  
minimum layer thickness : 294,0 µm



Inspection according to ASTM D 610-08

Evaluation Degree of Rust is present on surface

Rust grade:	10	less than 0,01%
General Rusting grade:	10-G	None
Spot Rusting grade:	10-S	less than 0,01%
Pinpoint Rusting grade:	10-P	None

Inspection according to ASTM D 714-02

Evaluation Degree of Blistering of Paints

Blistering grade:	10	None is present
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All test were preformed by Ing. Wilfried Hendrix



## **Appendix H: Proposed Changes to UFC 4-150-07**

The following text proposes revisions to UFC 4-150-07, Maintenance and Operation: Maintenance of Waterfront Facilities, that will facilitate DoD-wide implementation of the demonstrated technologies.

### **Chapter 3, “Materials and Preventive Maintenance”**

- Add a description of accelerated low water corrosion and microbial-influenced corrosion to the discussion on deterioration of steel. Appendix (A) provides background information on accelerated low water corrosion (ALWC).
- Add a new paragraph to include coating new steel sheet piling in-situ from a limpet cofferdam when a platform or pier will be installed overhead. The additional costs to installation will extend the service life of the steel bulkhead or/tie-back wall and reduce the life cycle maintenance costs.
- Add a coating system that universally stops corrosion from underwater to above the splash zone and is compatible with cathodic protection.

### **Chapter 5, “Inspection of steel sheet pile walls”**

Add a new Level IV inspection that includes the following tasks. The additional tasks will enable corrosion engineers and scientists to conduct root cause analysis of the corrosion mechanism(s).

- Inspections from a limpet cofferdam without requiring the use of a dive team
- Abrasive blast cleaning to SSPC 10 to reveal pin holes.
- Identify location, size and frequency of all holes to clearly identify scope of repairs.
- Record periodic steel thickness measurements every 30 cm horizontally and vertically at 5 meter intervals to clearly identify corrosion zones and scope of repairs.
- Collect physical samples of corrosion products and backfill behind holes to determine the whether corrosion originates from the land side or the water side.
- Conduct field tests for bacteria known to cause deterioration of steel
- Visually inspect tieback systems

- Add provisions to repair and protect the sheet pile wall against corrosion concurrent with the inspection to increase the value of the economic investment (see two phase project below).
- Add provisions to conduct torsion and tension tests every five meters. Replace tieback rods and bolts that fail. Replace tieback rods and bolts that fail.

## **Chapter 8, “Repair of Steel Structures”**

### **SR-12 (Proposed):**

**Problem:** Slight to moderate deterioration (less than 35 percent of cross sectional area) or damage has occurred to a steel sheet piling wall. Moderate to heavy deterioration (greater than 35 percent) or damage has occurred and holes have formed from approximately 2.0 meters below mean low water to the top of the sheet piling.

**Description of repairs:** Deploy a limpet cofferdam and dewater. Remove all marine growth, coating products, deteriorated steel and rust. Abrasive blast clean to SSPC-10 prior to inspection, weld repairs and coating. Use 3/8 inch ASTM A36 carbon structural steel for repairs. All welding shall be in accordance with AWS D1.1/D1.1M, Structural Welding Code, latest edition. All holes must be sealed watertight and the surface must be dry prior to welding repair plates. Weld reinforcing plates on steel less than 50% of original thickness, or as directed. Prior to coating application, inspect surface per coating manufacturer’s quality control instructions. Fill voids with putty, stripe coat sharp edges, and apply coating.

**Provisional work:** Conduct Level IV inspection.

**Coating system (from submerged to zone to top of sheet piling):** Underwater cure, two-component, 100% solid liquid polyamine epoxy: 1 coat 600  $\mu\text{m}$  to 1,000  $\mu\text{m}$  DFT. Fill voids with compatible putty variant and stripe coat sharp edges with compatible variant prior to coating.

**Application:** This method can be used as a repair or as a protection technique to prevent further corrosion. This method will stop the loss of backfill through the existing steel sheet piling wall. This method should restore most of the bearing capacity lost by the deterioration of the steel cross section. Where overhead obstructions impede overhead access of lifting equipment, this method may require economic evaluation.

**Future inspection requirement:** Normal inspection requirements should suffice. If inspection is from a limpet cofferdam, an inspection after 6 years and thereafter at 10 – 15 year intervals should suffice.

**Special skill requirements:** Work from a limpet cofferdam involves skills common to pile driving and ship painting. Work requires a competent person with training, experience, and knowledge of design, assembly, deployment and work from a limpet cofferdam.

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## **Appendix I: Proposed Synopsis for Negotiated Procurement**

## Proposed Synopsis for Acquisition

### IN-SITU COATING OF STEEL BULKHEAD SHEET PILING

#### 1. SYNOPSIS

<PLACEHOLDER name of contracting agency> (hereafter “Agency”) hereby notifies of the intent to issue a Request for Proposal (RFP) in a negotiated procurement for IN-SITU COATING OF IMMERSSED STEEL BULKHEAD SHEET PILING. This project is a multiphase construction project. The contract work consists of, but is not limited to, the following items of work: clean to near bare metal and inspect steel bulkhead sheet piling; repair holes/leaks watertight in sheet pile wall for the proper application of new coating; and, coat with a single coat, two-component solvent free polyamine cured epoxy. All work shall be conducted in a dry environment from a limpet cofferdam enclosure. The project will include an inspection of work twelve (12) months after project completion is part of the scope.

The site, located <PLACEHOLDER location of site>, is for <PLACEHOLDER facility’s mission>. <PLACEHOLDER number of phases> phases are planned in total, with phasing summary as follows: Base contract work consists of contract work on approximately <PLACEHOLDER> linear feet of steel sheet pile bulkhead; option work consists of contract work on an additional <PLACEHOLDER> liner feet for each option for a total of <PLACEHOLDER> linear feet.

The contractor must provide all management, supervision, labor, materials, supplies, and equipment (except as otherwise provided) and must plan, schedule, coordinate and assure effective performance of all construction to meet agency requirements. The contractor will perform the construction in accordance with the design specifications, drawings and terms and conditions of the contract. North American Industry Classification System (NAICS) Code is 237990 and the Size Standard is \$33.5 million. The estimated construction cost range is between \$1 - \$5 million. The Construction Performance Period shall not exceed <PLACEHOLDER> calendar days from receipt of a Notice to Proceed. Liquidated damages will be specified. Davis Bacon rates will be applicable to the construction and bonding is required. Please review all bonds and accompanying documents required to be submitted.

This negotiated solicitation is open to both small and large business firms. The firm (if not a small business concern) shall be required to present an acceptable small business, veteran-owned small business, service-disabled veteran-owned

small business, HUBZone small business, small disadvantaged business, and woman-owned small business Subcontracting Plan in accordance with Public Law 95-507, as part of its proposal. Consideration is open to established, qualified firms (including subcontractors), which currently have active, properly staffed offices within the continental United States.

Competitive formal source selection procedures will be used in accordance with FAR Subpart 15.3. The contract will be Firm Fixed Price. The "Best Value Continuum, Tradeoff Process" is the method that will be used to evaluate price and other factors specified in the solicitation, with the goal being to select the proposal that offers the best value to the Government in terms of performance, quality and pricing. The objective is to select the proposal that offers the most for the money, without necessarily basing selection on the lowest price. Bids shall include a description of work methods, table of contents of recommended health, safety and environmental plan, material safety data sheets, technical specifications, and other supporting documentation sufficient to describe work methods.

Bids shall include informational plans and drawings with sufficient detail for Agency to evaluate the following items: (1) determine that the method is suitable for its intended purpose; (2) worker safety; (3) loads imposed on the structure and on support equipment (barges, hosting equipment, etc.); (4) utilities; (5) assembly and deployment; (6) bills of material including equipment lists with descriptive information (7) outline dimensional drawings with weights, clearances, and equipment positions (8) primary materials of construction.

Evaluation by the Agency covers general design of details only, and if any change is made, which would cause members not to fit, or would not give sufficient strength, the offeror shall call the Agency's attention to the fact at once, in writing, so that corrections may be made. If the offeror fails to do this, the sole responsibility shall rest upon the offeror. Submission on the offeror's drawings, even though approved, shall not relieve the offeror from the responsibility of performing the work in accordance with the specifications. Any details not sufficiently shown on the submittals will be furnished to the offeror by the Agency upon request. Confidential, proprietary or patented technology shall be identified in accordance with FAR Subpart 15.6.

The Technical Evaluation Factors are:

- 1. EXPERIENCE .** (1) The offeror must demonstrate its past organizational experience as a General Construction (GC) Contractor responsible for the renovation of at least 1,500 square meters immersed steel bulkhead sheet piling, within the past five (5) years, which is comparable in nature, type, and complexity

to the project in this solicitation, and meets all the following characteristics: (a) work was performed on immersed z-piling 2.0 meters below mean low water along navigable waterways on the waterside; (b) The project met one (1) of the following criteria: (i) The project size was not less than 500 square meters, or (ii) The construction cost at award of the construction contract was not less than \$2 million for the complete renovation. (2) The offeror may demonstrate its experience as a General Construction (GC) Contractor responsible for the construction of five (5) additional projects within the past ten (10) years, which are comparable in nature, type, and complexity to the project in this solicitation. (3) The offeror shall submit Data and/or Information for each Project (three minimum) presented, in accordance with the RFP.

**2. PAST PERFORMANCE.** This factor considers the extent of the offeror's past performance with reference to such aspects as costs, timeliness, and technical success as part of the consideration. Consideration includes: (1) The offeror has experience as a General Construction (GC) Contractor responsible for the construction of at least three (3) marine construction projects, within the past five (5) years; (2) The offeror shall submit the following information for each submitted project. Give project title, location and reference who may be contacted regarding the quality of your performance. Indicate name, title, company name, current company address, and phone number of each reference.

**3. CONTAINMENT SYSTEM.** This factor considers the containment system being proposed by the offeror to execute the work contained in the contract drawings and specifications. Design shall be constructed so as to keep the structure free from water and to safely permit inspection, repair, and coating of the structure to be carried to the depths indicated on the plans. Contract work must (1) not be impeded by water standing or flowing within the work platform; (2) not impede port operations and waterway traffic. The containment system must (1) provide dry access to locations on plans; (2) provide a stable work platform to conduct welding, abrasive blasting, and other maintenance activities; (3) provide safe entry and egress; and (4) have the capability to safely and rapidly achieve a dry, salt-free surface underwater. Considerations include (1) the structural integrity of design, (2) sealing technology, (3) worker safety and comfort, and (4) ventilation.

**4. KEY PERSONNEL.** This factor considers the qualifications of the key personnel proposed by the offeror to execute the contract requirements for the positions proposed. Offerors must submit resumes of the individuals proposed for the following positions: Contract Executive, Project Manager, General Superintendent, Quality Control Supervisor and Competent Person in Charge of . Considerations include: (1) Educational background; (2) Experience on similar projects in a position comparable to that for which they are being proposed; (3)

Certification or professional registration held by the individuals proposed for key personnel positions. training, experience, and knowledge of design, assembly, deployment and work operations of the work platform(s);

**5. MANAGEMENT PLAN & SCHEDULE .** This factor considers the plan being proposed by the offeror to execute the work contained in the contract drawings and specifications. The Offeror must submit a proposed total contract duration in calendar days, which shall not exceed <PLACEHOLDER> calendar days from the Notice to Proceed. The duration proposed by the offeror, if successful on this procurement, shall become the official time of performance for this contract. < PLACEHOLDER Liquidated damages will apply.>

Considerations include: (1) Submission of a detailed logic diagram, arrow-on-arrow (minimum 100 activities), illustrating the proposed sequencing of work and clearly defining the critical path. Submittals, including shop drawings and samples and long lead time items should be indicated as separate activities; (2) Submission of a tabular schedule printout indicating, at a minimum, activity, activity duration and total float; (3) Submission of a narrative management plan describing how the offeror intends to execute the work in the field; (4) Submission of equipment and utility requirements for the following activities: (a) deployment of work platforms; (b) bulkhead Repair; (c) surface preparation; and, (d) coating application. Particular attention should be placed on the sequencing of work and on how the offeror intents to manage their subcontractors in order to ensure a smooth working relationship with the facility owner/tenant. The offeror should also discuss their procedures to ensure strict quality control relative to both workmanship and materials.

**6. ENVIRONMENTAL MITIGATION METHODS.** This factor considers the method of collecting debris. The containment system must contain all debris and fugitive emissions Where coating removal or coating application is being conducted in the splash zone, special care will be provided to capture any material removed from the coated area. The containment enclosure must confine spent materials, aerosols, dust and other debris generated: (1) during abrasive blasting operations; (2) when vacuuming the steel surfaces on the structure in preparation for coating application; (3) when collecting and removing debris; and (4) when applying the new coating. Considerations include (1) best management practice to prevent visible emissions or releases of spent materials, dust or other debris into the environment; (2) provisions for water pollution control.

**7. HEALTH AND SAFETY PLAN.** This factor considers the health and safety plan proposed by the offeror to execute the contract requirements. The offeror must submit (1) its health and safety plan; and (2) resume of competent person(s) for confined spaces proposed by the offeror. Considerations for the health and safety plan include (1) conformance to statutory regulations; (2) written risk

analysis and protective measures for hazardous conditions that may arise during execution of contract work including, but not limited to (a) working in confined spaces and trench shields (b) abrasive blasting and coating activities; (c) cleaning and welding and activities; (d) heavy equipment operations; and (e) working over water or from a barge. Considerations for the competent person include (1) training, experience, and knowledge of design, assembly, deployment and work operations of the containment system work platform(s); (2) use of protective systems; (3) ability to detect: (i) conditions that could result in structural failure (ii) failures in protective systems; (iii) hazardous atmospheres; and (iv) other hazards including those associated with contract work; and (v) have the authority to take prompt corrective measures to eliminate existing and predictable hazards and stop work when required

**8. SUBCONTRACTING PLAN.** The Agency is committed to assuring that maximum practicable opportunity is provided to small, small disadvantaged, and women-owned small business concerns to participate in the performance of this contract consistent with its efficient performance. Agency expects any subcontracting plan submitted pursuant to PLACEHOLDER (FAR 52.219-9, or as applicable), Small, Small Disadvantaged, and Women Owned Small Business Subcontracting Plan, to reflect this commitment. Consequently, an offeror, other than a small business concern, before being awarded a contract exceeding \$500,000 (\$1,000,000 for construction) will be required to demonstrate that its subcontracting plan represents a creative and innovative program for involving small, small disadvantaged, and women-owned small business concerns as subcontractors in the performance of this contract. If selected for award, the offeror's subcontracting plan should be ready for approval without the need to obtain additional information. The Agency goals for subcontracting are as follows: small businesses at least 41% of total subcontracting planned; small disadvantaged businesses at least 12% of small business subcontracting planned and small women-owned businesses at least 5% of small business subcontracting planned.

This will be a standard RFP where Technical and Price are to be submitted same date and time, but separate packaging. In accordance with the requirements of the RFP, proposals shall be submitted no less than 30 calendar days from issuance of the RFP; projected date of <PLACEHOLDER>, by <PLACEHOLDER>, EST, to the following address: <PLACEHOLDER>. This solicitation is not set-aside for small business concerns. However, this procurement is being made under the Small Business Competitiveness Demonstration Program. All qualified responsible firms are encouraged to participate in this procurement. Small, veteran-owned small, service-disabled veteran-owned small, HUBZone small, small disadvantaged, and women-owned small businesses are encouraged to

participate as prime contractors, or as members of joint ventures with other small businesses.

## 2. PRICE

ITEM	DESCRIPTION	NO. UNITS	UNIT	UNIT PRICE	EXTENSION
1	Mobilization	1	LS		
Base Bid					
2	Price for the entire work, complete in accordance with drawings and specifications, but excluding work described in Bid Items 3 & 4	1	LS		
3	Surface Preparation & Coating Application	500	LF		
4A	Reinforcing plates, 1000x50x6mm, equipment, material and labor to bend, fit and weld plates; grout voids	100	PC		
4B	Patch Plates, equipment, material and labor to seal holes watertight, fit and weld 200x200x6 mm flat patch plates per repair specification	200	PC		
4C	Doubling plates bent to fit existing SSP, 1.000highx250x250X6mm, equipment, material and Labor to fit and weld plates	100	PC		
4D	Injection of un-shrinkable cement grout or epoxy resins Between doubling plates and old steel	200	KG		
5	Use of complete set of equipment and labor for Unforeseen work	50	HR		
6	TOTAL BASE BID ITEMS 1 – 4, Bulkhead Coating	500	LF		
6	Inspection 12 months after work complete	1	LS		
Option 1:					
	Unit Price for Additional Work, excluding Weld Repairs	1,000	LF		

## 3. DESCRIPTION

This specification is for products and services to renovate immersed steel sheet piling. Renovation shall include inspection, repair, and application of corrosion protection as shown on the Agency's drawings. Work shall be conducted in a dry environment in-situ. All work shall be conducted from <PLACEHOLDER (a barge supplied by the contractor/shore.)> The

## 4. CONDITION OF THE BULKHEAD

< PLACEHOLDER Note to Specifications Writer: In the absence of actual inspection reports, the following minimum information should be provided. The information will serve as a baseline for estimators.>

The bulkhead is <PLACEHOLDER uncoated / coated> <PLACEHOLDER Specify type, location and thickness of coating, if any.>

Table 1 is the Agency's visual assessment of the general bulkhead surface condition.

**Table 1 – Agency's estimate of the General Bulkhead Surface Condition**

Elevation	Degree of Paint Blistering (ASTM D610)	Rust Degree (ISO 8501-1)	Thickness of rust layer (mm)	Per cent remaining steel thickness under uniform corrosion
MHW to Top				
MLW to MHW				
MLW-2.0 to MLW				

The contractor can expect to encounter localized areas of unsound steel and holes below the waterline. The size, location and frequency of holes are shown on the Agency's Plans.

## 5. TEST SECTION

The Contractor shall initially complete a 100 linear foot test section of cleaning, patching, repairing and coating. This test section shall be used to verify the adequacy and make necessary adjustment to the initial work plan. The test section will also be used to verify current bulkhead condition, and determine if adjustments to the patching and repair criteria are required. The standard of quality for the remainder of work will be established by the test section.

Contracting Officer approval is required prior to any additional contract work.

## 6. GENERAL RESPONSIBILITIES OF BIDDERS

- A. **Sole Responsibility.** Of essence, it is the sole responsibility of the contractor to supply a safe and suitable working methods for contract work. Contract work shall meet all the requirements given in this Performance Specification, which include requirements for safety, form design features, structure, method and materials for construction, fitting out, stability, and operational efficiency.
- B. Work shall not interfere with waterway traffic or port operations.
- C. Representatives of Agency's facilities shall have safe access to the bulkhead for all inspections.
- D. The contractor shall use Generally Available Control Technology (GACT) and/or best management practices to mitigate emissions from welding, abrasive blasting, and other small sources of air pollution.

## 7. MOBILIZATION

Contractor shall provide all necessary movement of personnel, equipment, supplies and incidentals to the project site, for the establishment of all offices and other facilities necessary for work, on the project, and for all other work and operations which must be performed prior to beginning work on the various items on the project site.

## 8. PROJECT SCHEDULE

### A. Commencement of Work

1. The Contractor shall be required to commence base bid work under this contract within <PLACEHOLDER> calendar days after the Contractor receives the notice to proceed for the work.

2. The Agency has the right to award Options within 90 days of Notice to Proceed for the Base Bid

### B. Base Bid

1. Complete inspection, repair and coating application for <PLACEHOLDER minimum 10% of total work> linear feet not later than <PLACEHOLDER> calendar days after the date the Contractor receives the notice to proceed. The time stated for completion shall include final cleanup of the premises.

### C. Options

1. If awarded, the contract duration will be extended <PLACEHOLDER> calendar days for each option. The time stated for completion shall include final cleanup of the premises.

### D. Twelve Month Inspection

1. Twelve months after project completion, the contractor shall inspect the visible portion of the bulkhead above mean low water. The contractor shall remove, inspect, and replace underwater coupons

E. Working Days

1. Unless otherwise specified, the Contractor shall be permitted to perform the contract work between the hours of 7:00 am and 7:00 pm, Monday through Saturday.
2. Federal holidays (New Year's Day, Martin Luther King Jr's Birthday, Presidents Day, Memorial Day, Independence Day, Labor Day, Columbus Day, Veterans Day, Thanksgiving Day, and Christmas Day) that fall within the work week will not be considered as work days.
3. The Contractor shall provide at least a 24 hour advanced notification to establish when on-site work will commence and prior to restarting on-site work following any stoppage of work. Notification shall be provided by phone, or person, or in writing, and shall be given directly to the Agency.

F. Time Extensions for Unusually Severe Weather

1. In order for the Agency to award a time extension for unusually severe weather conditions, the following conditions must be satisfied:
  - a) The weather experienced at the project site during the contract period must be found to be unusually severe, that is, more severe than the adverse weather anticipated for the project location during any given month.
  - b) The unusually severe weather must actually cause a delay to the completion of the project. The delay must be beyond the control and without the fault or negligence of the Contractor.
  - c) The following schedule of monthly anticipated adverse weather delays is based on National Oceanic and Atmospheric Administration (NOAA) or similar data for the project location and will constitute the base line for monthly weather time evaluations. The Contractor's progress schedule must reflect these anticipated adverse weather delays in all weather dependent activities. For the purpose of this contract, unusually severe weather is defined as daily precipitation equal to or exceeding 0.5 inches and/or maximum daily temperature not exceeding 32 degrees F.

**Table 2. Monthly anticipated adverse weather delay work days based on (5) day work week.**

JA N	FE B	MA R	AP R	MA Y	JU N	JU L	AU G	SE P	OC T	NO V	DE C
7	4	2	2	2	2	2	2	2	2	2	3

2. Upon acknowledgment of the Notice to Proceed (NTP) and continuing throughout the contract, the Contractor shall record the occurrence of adverse weather and resultant impact to normal scheduled work. Actual adverse weather days must prevent work on critical activities for 50 percent or more of the Contractor's scheduled work day. The number of actual adverse weather delay days shall include days impacted by actual adverse weather (even if adverse weather occurred in previous month), be calculated chronologically from the first to the last day of each month, and be recorded as full days. If the number of actual adverse weather delay days exceeds the number of days anticipated in Table 2 above, the Agency will convert any qualifying delays to calendar days, giving full consideration for equivalent fair weather work days, and issue a modification to the contract.

#### G. Temperature and Dew Point Restrictions

1. Coating shall not be applied when the temperature of the steel below 50°F or when the air temperature is below 45°F and falling without prior approval from the Agency.
2. The Contractor should not apply paint until the temperature of the steel is at least 5° F (3° C) above dew point.

#### 9. SPECIFICATIONS

Measurements are in metric units.

Specification	Description
ASTM D 4417	Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel, Method B
ASTM D 1186	Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base
ASTM D 4541	Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
ISO 8502-3	Preparation of steel substrates before application of paints and related products -- Tests for the assessment of surface cleanliness -- Part 3: Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)

ISO 8502-4	Preparation of steel substrates before application of paints and related products - - Tests for the assessment of surface cleanliness -- Part 4: Guidance on the estimation of the probability of condensation prior to paint application
ISO 8502-6	Preparation of steel substrates before application of paints and related products - - Tests for the assessment of surface cleanliness -- Part 6: Extraction of soluble contaminants for analysis -- The Bresle method
ISO 8502-9	Preparation of steel substrates before application of paints and related products - - Tests for the assessment of surface cleanliness -- Part 9: Field method for the conductometric determination of water-soluble salts
ISO 8503-2	Preparation of steel substrates before application of paints and related products - - Surface roughness characteristics of blast-cleaned steel substrates -- Part 2: Method for the grading of surface profile of abrasive blast-cleaned steel -- Comparator procedure
ISO 19840	Paints and varnishes -- Corrosion protection of steel structures by protective paint systems -- Measurement of, and acceptance criteria for, the thickness of dry films on rough surfaces
SSPC-VIS	Digital photographs & comparison to photographic reference standard of surface condition
SSPC-AB	Abrasive Specification No. 1 for Mineral and Slag Abrasives
SSPC-VIS 1-89	Guide To Visual Standard for Abrasive Blast Cleaned Steel (Standard Reference Photographs)
SSPC SP-2	Surface Preparation Specification No. 2 for Hand Tool Cleaning
SSPC SP-3	Surface Preparation Specification No. 3 for Power Tool Cleaning
SSPC-SP 6/NACE No. 3	Joint Surface Preparation Standard for Commercial Blast Cleaning
SSPC-SP 10/NACE No. 2	Joint Surface Preparation Standard for near-white blast cleaning

Structural inspections shall conform to the following specifications:

Specification	Description
ASTM E 797	Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method
ASTM D610	Standard Test Method for Evaluating Degree of Rusting on Painted Steel
ISO 8501-1, Part 1	Preparation of steel substrates before application of paints and related products -- Visual assessment of surface cleanliness -- Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings

Weld repairs shall conform to the following specifications:

Specification	Description
ASTM A242/A242M	High-Strength Low-Alloy Structural Steel
AWS D1.1	Structural Welding Code – Steel
AWS Z49.1	Safety in Welding and Cutting and Allied Processes

Surface preparation and coating shall conform to the manufacturer's specifications for coating application and includ the following specifications.

As a minimum, the Health and safety plan shall conform to the applicable section of the following regulations.

- Code of Federal Regulations 29 CFR Chapter XVII paragraph 1926
- U.S. Army Corps of Engineers Safety & Occupational Health Standard EM 385-1-1

## 10. STANDARDS FOR WORKING PLATFORMS

A. The intent of this standard is to design a work platform in full compliance with the requirements given in this specification for quality in every aspect which, where necessary for the specific role of the structure, may be over and above that is normally required by statutory and classification rules.

B. Working platforms for contract work shall

1. Provide dry access to locations on plans.
2. Provide a stable work platforms to conduct welding, abrasive blasting, and other maintenance activities
3. Provide safe entry and egress.

C. Design shall be constructed so as to keep the structure free from water and to safely permit inspection, repair, and coating of the structure to be carried to the depths indicated on the plans. Contract work shall not be impeded by water standing or flowing within the work platform.

D. A licensed engineer with relevant experience shall certify the design.

E. Confidential, proprietary or patented technology shall be identified in accordance with FAR Subpart 15.6.

F. Resisting forces should be at least 1.5 x the driving forces. Vendors shall state the basis of calculations and safety factors.

G. Work platforms for contract work shall not impede port operations and waterway traffic.

H. All electrically operated equipment shall be suitable for submersible operation

I. The work platforms shall have adequate provisions for the following functions:

1. Adequate ventilation for welding and abrasive blasting operations

2. Containment to avoid contamination of air and water

3. Illumination

J. Design should be fabricated and assembled to the maximum extent practical. Loose parts, electrical components, and liquids shall be shipped in packages that can be handled with normal construction equipment

K. Assemblies greater than 25 kilograms (60 lbs.) should be provided with the lifting means for transport and deployment.

L. Rules and Regulations

1. All materials of construction, fittings, and electrical equipment shall be produced and installed in accordance with an accredited national or international standard, (e.g. ASTM, British Standards, JIS, ISO).

2. Quality and standards of construction not mentioned in this Specification shall comply with international standards or rules.

M. Contractors shall provide informational plans and drawings with sufficient detail for Agency to evaluate the following items:

1. Determine that the method is suitable for its intended purpose

2. Worker safety

3. Loads imposed on the structure and on support equipment (barges, hosting equipment, etc.)

4. Utilities

5. Assembly and deployment

6. Bills of material including equipment lists with descriptive information

7. Outline dimensional drawings with weights, clearances, and equipment positions

8. Primary materials of construction

N. **Safety Requirements.**

1. A means of emergency access/escape shall be provided.
2. All working platforms shall be stable and capable of bearing 200 pounds per square foot (100 kg per square meter)
3. All working platforms shall have guard railing and in accordance with OSHA requirements.
4. All working platform surfaces shall provide slip resistance.
5. All guardrails shall be coarse grip. All platforms and guardrails shall be hot-dipped galvanized.

11. **STANDARDS FOR INITIAL CLEANING**

Prior to weld repairs, clean to SSPC-SP 3 (hand tool and power tool clean to remove loose rust). Abrasive blast to SSPC-6 (commercial blast cleaning) and sufficient for inspection and weld repairs.

12. **STANDARDS FOR INSPECTION**

A. As a minimum, the Contractor shall measure and record the data listed below. The Agency will use the data to assess the structural integrity of the bulkhead and evaluate corrosion protection. The Agency shall analyze existing coatings and materials for hazardous materials.

1. Residual steel thickness using ASTM E 797 - latest edition,
2. ASTM D 1186 Dry Film Thickness of existing coatings
3. “Standard Test Method for Evaluating Degree of Rusting on Painted Steel”, ASTM D610 including “Standard Test Method for evaluating Degree of Blistering of Paints”, ASTM D714
4. Digital photographs & comparison to photographic reference standard SSPC-VIS of surface condition
5. Size and location of holes

6. Degree of pitting including depths, locations and frequency of pits

7. Digital photographs and descriptive text

B. Standard Test Frequency

1. ASTM E 797: at the in-pan, out-pan, and web of each pile at 0.5 m increments from the top of bulkhead; each measurement shall be the average of 4 measurements in a 50 mm diameter.

2. ASTM D 4417: per coating manufacturer's instructions

3. ASTM D 1186 Dry Film Thickness 1 test/10 linear feet

4. Photographs

13. STANDARDS FOR REPAIRS

A. Seal all holes and all leaks watertight.

B. Weld steel reinforcing plates over any unsound metal.

C. Weld steel patch plates over any holes.

D. All welding and welding quality control shall be in accordance with AWS D1.1/D1.1M, Structural Welding Code, latest edition.

E. Use 6 mm ( $\frac{1}{4}$  inch) weathering structural steel in conformance with ASTM A242/A242M.

F. Where repairs require welding steel reinforcing plates to the bulkhead, each plate shall extend a minimum of 1-inch in all directions beyond the limits of the hole and any unsound metal surrounding the hole, and shall be fabricated to match the shape of the sheet piling <PLACEHOLDER as shown in Figure ( )>.

G. The limit of unsound metal shall be defined as the extent of bulkhead surrounding the hole which exhibits a section loss of greater than 50% when tested in accordance with ASTM E797, or as directed by the Agency.

H. Where multiple holes occur in close proximity, the Agency will make the determination whether one plate or multiple plates shall be used.

I. Each repaired area will require inspection and approval by the Agency prior to application of the protective coating.

J. After welding, voids behind the reinforcing plates shall be injected and filled with cement grout or epoxy resin.

14. STANDARDS FOR SURFACE PREPARATION

- a. Contractor will abrasively blast the surfaces to at least SSPC-SP10 prior to coating. The backside of cross frame assemblies that are 3 inches (75 mm) or closer to back walls may be blast cleaned to SSPC-SP6.
- b. Roughness profile shall be nominally at least ISO 8503-2 segment 1.
- c. The Contractor will measure chlorides and dust to insure that the concentrations of these contaminants are less than the specified levels allowed.
- d. If necessary, rinse with fresh water and dry. The Contractor may use a rust inhibitor.
- e. The Contractor should paint steel surfaces the same day that they are blast cleaned. If the Contractor does not paint a surface the same day that it is blasted, the Contractor may have to re-blast the surface. The Contractor will re-test the surface for chlorides, dust, and condensation.

A. Due to the possibility of condensation, any abrasive blasting done when the steel temperature is less than 5° F (3° C) above the dew point must be re-blasted when the temperature of the steel exceeds 5° F (3° C) above the dew point. The contractor shall measure and record surface temperature, ambient temperature, humidity, dew point and wet bulb temperature per ISO 8502-4

B. Chloride concentrations shall not exceed 60 mg/m<sup>2</sup>. The Contractor will measure and record chlorides at the start of each phase per ISO 8502-6. Salt concentrations shall not exceed 90 mg/m<sup>2</sup>. The Contractor will measure and record salts at the start of each phase per ISO 8502-9.

C. After the Contractor completes abrasive blasting, all abrasive and dust will removed from the surface to be painted. The Contractor will remove dust and abrasive from any adjacent painted surface and structure. Dust shall not exceed “3” per ISO 8502-3.

- f. The Contractor will check abrasives and compressed air to insure that they are free of oil and chlorides.

- g. Inspect surface preparation (clean steel, surface profile) and test for salts, moisture in accordance with coating manufacturer's instructions.
- D. Fill flush to the steel surface any voids or pits that are greater than 70% of the original steel thickness.

## 15. COATING SPECIFICATION

A. Acceptable coatings include **Humidur® ML** or approved equal. Color samples shall be submitted to and be approved by the Agency.

B. Manufacturer's Quality Control

1. Contractor shall submit verifiable evidence of coating manufacturer's quality control program, including the following items:

- a) Quality control system for the manufacture of the coating products;
- b) Laboratory with equipment and personnel employed and qualified in the field of corrosion and anti-corrosion protection as well as concerning the execution of the necessary tests as far as quality and control are concerned; and
- c) Historical inspection reports of coatings applied on immersed steel to verify coating durability under actual conditions. Include contact information, description of the work, the scope of the project, and the order value.

2. Coating manufacturer shall have the ability to provide an insurance policy of not less than ten (10) years on coating systems applied under manufacturer's supervision.

3. The coating shall be a two-component, solvent free and coal tar free epoxy system with high corrosion and abrasion resistance.

4. The coating shall have a verifiable toxicity report stating that the coating is non-hazardous to aquatic life during and after curing.

5. Nominal coating thickness shall be 600 µm, minimum coating thickness shall be 400 µm

- a) Technical properties

- Content of solid material : 100 % by weight at ambient curing
- No flashpoint can be observed using Seta flash open cup between 32 and 230° F
- Pot life at 73° F = 45 minutes, at 86° F = 30 minutes
  - b) Mechanical properties:
- Dielectric resistance: > 19 KV per NACE RP-02-74
- Adhesion strength: > 2117 psi (> 14,6 MPa) per ASTM D 4541
- Resistance to cathodic disbanding: - 1,100 mV/Cu/CuSO<sub>4</sub> reference electrode per ASTM G 8

6. Coating Handling Procedures

- a) All paint shall be delivered to the shop or job site in original, unopened containers with labels intact. Minor damage to containers is acceptable provided the container has not been punctured or the lid seal broken. The Agency shall retain a complete kit selected at random for more testing. The sample shall be furnished at the Contractors expense and turned over to the Agency.
- b) Each container of paint shall be clearly marked or labeled to show paint identification, date of manufacture, batch number, analysis of contents, identification of all toxic substances and special instructions.
- c) All containers of paint shall remain unopened until required for use. Those containers which have been previously opened shall be used first. The label information shall be legible and shall be checked at the time of use.
- d) Paint which has gelled or otherwise deteriorated during storage shall not be used. All coating shall be stored for protection from the weather and from excessive hot or cold temperatures as recommended by the manufacturer. The paint must be stored to conform to City, County and State Safety Codes for flammable paint materials. The oldest paint of each kind shall be used first. In every case, paint shall be used before its shelf life has expired. In order to use paints which have exceeded their shelf life or have no stated shelf life and

are more than one year old, the manufacturer must certify that the paint is still suitable for use.

7. Coating application
  - a) Application and recoating shall be according to manufacturer's instructions.
  - b) The Contractor will apply each coat of paint as a continuous film of uniform thickness. It is to be free of defects such as holidays, runs, sags, etc.
  - c) Contractor will repair defects resulting from application. The Agency will accept small number of runs around bolts and areas where the cross frames attach to beams.
16. ENVIRONMENTAL COMPLIANCE
  - A. No discharge of pollutants into the environment.
  - B. No discharge into the atmosphere from abrasive blasting for a period aggregating more than three minutes in any one hour which is dark or darker in shade as that designated as No. 2 on the Ringlemann Chart, as published by the United States Bureau of Mines.
  - C. 40 CFR Subchapter C, parts 100-149 - Federally Promulgated Water Quality Standards
  - D. Contain spent materials, aerosols, dust and other debris generated:
    1. during abrasive blasting operations;
    2. when cleaning the steel surfaces on the structure in preparation for coating application;
    3. when collecting and removing debris and
    4. when applying the new coating.

## 17. CONTAINMENT AND WASTE DISPOSAL

- A. Containment
  1. Primary method of collecting debris shall be a containment enclosure. The enclosure provides localized containment at the point of collection and conforms to the surface. Secondary method shall be to channel debris within the enclosure to a central removal location.

2. Where coating removal or coating application is being conducted in the splash zone special care will be provided to capture any material removed from the coated area. The containment enclosure shall be used to confine spent materials, aerosols, dust and other debris generated:
  - a) during abrasive blasting operations;
  - b) when vacuuming the steel surfaces on the structure in preparation for coating application;
  - c) when collecting and removing debris and
  - d) when applying the new coating.

B. Contractor generated Waste Materials

Abrasive blasting debris picked up at the end of the day and disposed of properly at Contractor's expense. If the Contractor generates toxic debris, the Contractor must dispose of it within 60 days.

C. Hazardous Materials

In the event the contractor unexpectedly encounters on the site material reasonably believed to be classified hazardous substances/materials which have not been rendered harmless, the contractor shall immediately stop work in the area affected and report the condition to the Agency. The work in the affected area shall not thereafter be resumed except by written agreement of the Agency's and contractor if in fact the material is classified hazardous substances/materials which have not been rendered harmless. The work in the affected area shall be resumed in the absence of any classified hazardous substances/materials or when it or they have been rendered harmless.

18. QUALITY CONTROL

The Contractor shall submit his quality control program to the Agency for approval. Personnel performing quality control shall be submitted for approval. The Contractor shall record all documentation using the Coating Inspector's Logbook. The Logbook shall be made available for review by the Inspector at all times. Provide the final copy of the completed log book at no additional cost to the Inspector. The Contractor shall stop work at pre-established hold points. For example, after surface preparation, between priming, intermediate, finish and such other points deemed necessary by the Inspector. The Inspector may elect to waive any hold point. This in no way releases the Contractor from the requirements set forth in this specification. Safe access and proper lighting to all areas to be inspected, both on and off the Job Site property shall be provided by the Contractor at no additional cost to the Agency.

Any defects found not meeting the requirements of this specification shall be repaired at no cost to the Agency.

In addition the Contractor shall verify at a minimum but not limited to the following:

- Provide Inspector with copies of all documentation; and,
- Such other request as directed by the Inspector.

**19. INSPECTION TWELVE (12) MONTHS AFTER WORK COMPLETE**

In order to monitor the coating behavior after the completion of the work, the contractor shall install two (2) coupons on the face of the seawall underwater for exposure. Contractor shall install coupons at locations depicted on the Agency's Plans. One coupon shall be coated using the same process that was used for the sheet pile on the seawall. The second coupon shall be installed untreated.

After twelve (12) months, the contractor shall remove one half the total number of treated and one half the total number of untreated coupons for inspection. The remaining coupons remain on the bulkhead for long-term exposure analysis by the Agency. The contractor shall provide photographs and evaluation of the coupons per ASTM D610, ASTM D 714, and ASTM D 1645.

**20. MEASUREMENT AND PAYMENT**

Contract work will be measured for payment by the linear foot of bulkhead cleaned and coated. All costs in connection therewith shall be included in the contract unit price for Item "Bulkhead Coating." Included in this Price Item are the costs in connection with repairs and patching holes in the bulkhead.

# REPORT DOCUMENTATION PAGE

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<b>13. SUPPLEMENTARY NOTES</b>								
<b>14. ABSTRACT</b> <p>The Department of Defense (DoD) spends over \$100 million annually maintaining and repairing waterfront infrastructure, including corroded steel sheet pile structures located in warm, salt-water immersion and areas susceptible to accelerated low-water corrosion. Once designed as temporary structures, many now support permanent requirements and must be repaired in place. Conventional underwater repair and coating operations are accomplished by specialized divers at very high cost. This project investigated a cost-saving emerging technology called a limpet cofferdam, which is readily positioned below the waterline to provide workshop-like conditions for repair technicians, and is rapidly movable along submerged sheet pile structures. Also demonstrated was a highly durable, single-coat amine epoxy system that fully cures in immersion.</p> <p>Limpet deployment and dewatering was completed in 30 minutes or less, and leaks into the workspace through damaged sheet pile were sealed in 5–30 minutes, depending on perforation size and other variables. The coating was found to be readily sprayable with only minimal pinholing, and fully cured under water. Literature indicates that this coating can be expected to have a 25–30 year service life. The calculated return on investment for these technologies is 14.70, with higher potential return when planning includes the recommended site-assessment methods.</p>								
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